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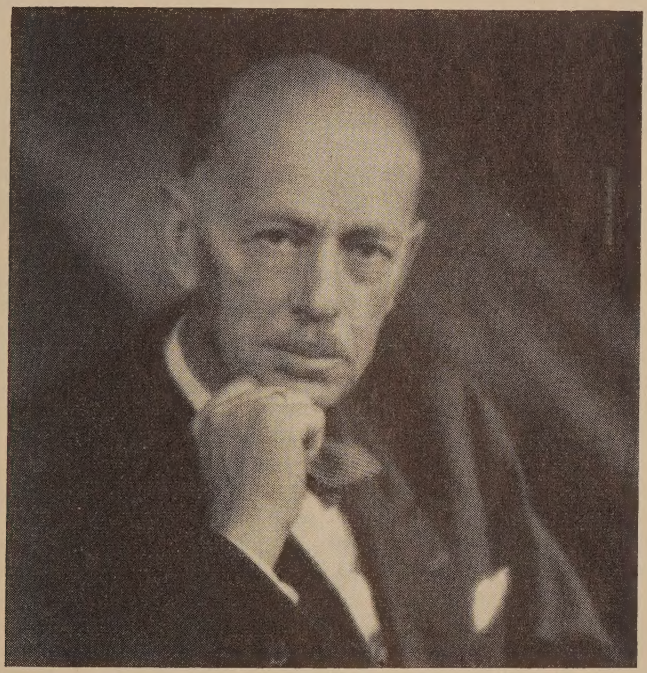


Harald Ulrik Sverdrup
1888—1957

Professor Dr. phil. Harald Ulrik SVERDRUP died suddenly on 21. August 1957. His untimely death will be felt as a great loss to all his many friends and colleagues throughout the world.

A few days before he died he participated in the meeting of the Norwegian Geophysical Association, which celebrated its 40th anniversary, and of which he was one of the founders. He opened the meeting with a lecture on the tractive effect of the wind on the polar ice. This was based on recent studies which he had just prepared for publication. He was still scientifically active in spite of the heavy administrative duties which in later years took up so much of his time and attention.

H. U. SVERDRUP was born in Sogndal, in Sogn on 15. November 1888. He took his degree at the University of Oslo in 1914, after he had become scientific assistant to Professor V. BJERKNES in 1911; this event determined his subsequent career in science. In 1914 he followed BJERKNES to Leipzig and there he completed his thesis on the North Atlantic Trade Winds. He obtained his doctorate from Oslo University in 1917. He then agreed to take charge of the scientific work on Roald AMUNDSEN's North Polar Expedition with the "Maud" from 1918 to 1925. On this expedition a large programme of geophysical observations was successfully carried through. The meteorological and oceanographical observations especially produced very important results.

When SVERDRUP returned from the Arctic, he succeeded V. BJERKNES as professor of meteorology at the Geophysical Institute in Bergen. This was done on the understanding that he should be able to devote himself to the analysis of the observations made on board the "Maud". These studies eventually resulted in the publication of five large volumes, of which SVERDRUP himself wrote the major part. While on board the "Maud" he prepared a treatise on the Dynamics of the Tide on the North Siberian Shelf. Current measurements had shown that the tidal currents rotated with nearly constant velocities in a clockwise direction, and that the currents were slowest near the bottom, and near the surface, where the ice cover was fixed. He was able to show that these conditions could be explained as a combined effect of the Earth's rotation and the turbulent friction in the sea.

As a result of his study of the water masses on the Siberian Shelf, his interests turned more from meteorology to oceanography, and it is probably to this branch of knowledge his most important contributions have been made.

In 1931 he was in charge of the scientific work on the Wilkins Elsworth North Polar Expedition on board the submarine "Nautilus", and in the same year he was elected to a research fellowship in oceanography at the Christian Michelsen Institute in Bergen. This did not mean that he abandoned meteorology altogether, and the interaction between the atmosphere and the ocean is a theme that often recurs in his investigations.

In 1934, in conjunction with H. W. AHLMAN, SVERDRUP made glaciological studies of the snowfields of West Spitsbergen. Here he made observations of fundamental importance on the heat exchange between the snow surface and the air, and of the temperature in the interior of the glaciers. The results of these investigations were also valuable in connexion with his later work on the evaporation from the oceans.

In 1936 he accepted the directorship of the Scripps Institution of Oceanography; this gave him the opportunity to start extensive oceanographical investigations in the Pacific, a region which had

already attracted his attention when he analysed the observations made by the Carnegie Expedition. In La Jolla SVERDRUP gathered round him a number of research workers who thanks to his inspiration have since made important contributions to physical oceanography. His researches in those years were centred mainly on problems dealing with the interaction between the atmosphere and the sea, and with turbulence and upwelling, but he also helped with the work on several papers dealing with marine biology.

Among the war-time tasks in which he took a leading rôle were the construction of current charts for use on life-saving rafts and the development of methods for predicting sea and swell. The increasing activity in oceanography demanded more trained scientists, and SVERDRUP therefore organized a full course in oceanography. This eventually led to the publication of the well known textbook, "The Oceans, their Physics, Chemistry and General Biology", in which the chapters on physical oceanography were his own contribution. The chapter entitled "The Water Masses and Currents of the Ocean" is probably the best survey of the subject at present available. Some of the chapters were re-written and published as a separate book, "Oceanography for Meteorologists".

When the war ended, SVERDRUP returned to Norway, and in 1948 he assumed the directorship of the newly established Norwegian Polar Institute and at the same time he was elected to the Chair of Geophysics at Oslo University. Both these institutions profited from his exceptional administrative ability. Soon after his return to Norway he organized the Norwegian-Swedish-British Antarctic Expedition, and later he visited the expedition at Maudheim, to see that all was going according to plan. The present Norwegian Antarctic Expedition is also due to his initiative.

At the University he became director of the summer school for foreign students and for 3 years he acted as Dean of the Faculty of Science. He was recently elected Pro-rector of the University. SVERDRUP always played a very active part in international scientific organizations. He served as President of the International Association of Physical Oceanography and, at the time of his death, he was President of the International Council for the Exploration of the Sea. His international reputation and his great administrative ability clearly marked him out as the right man when the Norwegian Government had to find a Chairman for the India Relief Organization, and he made several visits to India to put into effect the programme for improvement of the fisheries on the coast of Travancore.

Outside his professional occupations he had widespread interests. During the "Maud" Expedition he had an opportunity to live for nearly eight months among the Chukchi people, and he wrote a most interesting account of their life and beliefs. In some of his lectures, too, he showed his interest in the philosophical aspects of science.

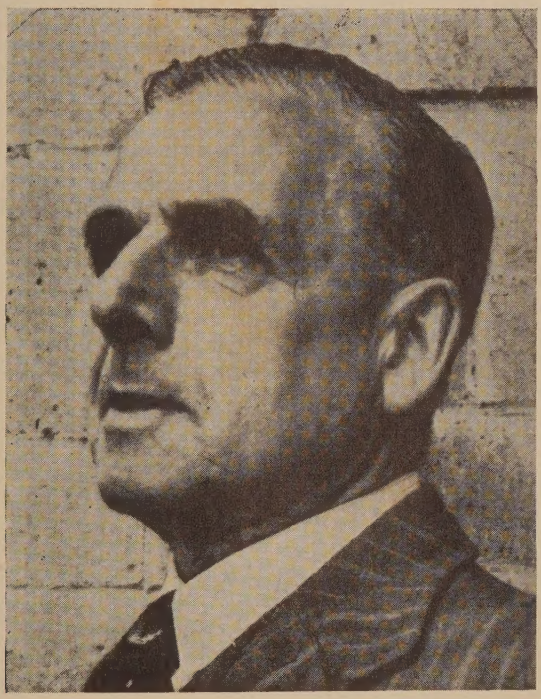
At the time of his death SVERDRUP ranked in the first place among the oceanographers of the world, and many honours have been bestowed upon him.

For his 60th birthday his friends and colleagues dedicated to him a large volume containing 41 papers from every branch of oceanography and meteorology. During his sojourn in the United States, he was elected a member of the National Academy of Science, and he received a honorary doctorate from the University of California.

A considerable number of medals of honour were awarded to him in recent years, among which may be mentioned the Agazzis Medal, the British Royal Geographical Society's Medal, Bruce Memorial Medal, Vega Medal, Bowie Medal, Meteor Medal, Ritter Medal, and the U.S. Navy Distinguished Public Service Medal. He was Commander of the Order of St. Olav, of the Danish Order of Dannebrog, and of the Swedish Nordstjerne Order. He has been member of the Norwegian Academy of Science since 1927.

As an academic teacher SVERDRUP was pre-eminent; he easily made contact with his students, whom he treated more as friends than subordinates. He had a strong sense of humour, and his humanity and charm of manner made him a highly valued friend and colleague. He will be deeply missed by his wife Gudrun SVERDRUP and by his many friends.

J. E. Fjeldstad



Harold Thompson
1890—1957

Harold THOMPSON, the son of William THOMPSON, schoolmaster in Aberdeen, was born there on 12. October 1890. He graduated Master of Arts at the University of Aberdeen in 1912 and after a year of school-teaching returned to his *Alma Mater* to read science for the Bachelor's degree.

A war career of distinction, in which he attained the rank of a captain of artillery and was twice mentioned in despatches, interrupted THOMPSON's academic studies for five years, but, by his own confession later to the writer, strengthened his resolve to make a career in scientific research. In 1920 he graduated Bachelor of Science with special distinction in chemistry and zoology. A short period as assistant

in the Department of Biochemistry at the University of Edinburgh was followed by his appointment, in 1921, to the research staff of the then Fishery Board for Scotland (since 1939, the Fisheries Division of the Scottish Home Department) at their Marine Laboratory in Aberdeen. Here THOMPSON quickly made his mark as an independent, indefatiguable, and painstaking research worker. He was promoted to senior rank in 1925.

Seized of the concept, Scandinavian in origin, of scale rings as a reliable index of the age of individual fishes, and of the import of this in the assessment of fish populations, THOMPSON soon established its validity in respect of North Sea haddock. His intensive and now classical work on this species formed the basis of remarkably accurate prognostication of the haddock fishery of the region, and provided the incentive to similar investigations elsewhere. In 1927 he was awarded the degree of Doctor of Science by the University of Aberdeen for a thesis, "On the local growth rates, age analysis and migrations of the haddock".

While still a member of the Scottish research staff, THOMPSON further established his international reputation as an original and skilful research worker by four official publications on "The Tunicata of the Scottish Area", before, in 1930, being called upon by the British Empire Marketing Board and the Government of Newfoundland, jointly, to undertake a survey of the Grand Banks and Newfoundland fisheries. The result of this survey was that, a year later, THOMPSON was offered, and accepted, the first directorship of fisheries research in Newfoundland. From Bay Bulls, near St. John's, where he lost no time in establishing a laboratory and in engaging a team of research workers, THOMPSON, with the trawler, "Cape Agulhas", as a research ship, set about the systematic study of the great cod fisheries in particular of the Newfoundland region, showing the bearing of different water-mass intrusions, with their different physical characteristics, principally of temperature, upon the geographical locations and biological compositions of the fisheries of the region as a whole. Other fisheries, for example, haddock, herring, caplin, salmon, squids, lobster, shrimps, and prawns also received close attention, while plankton and hydrographic studies, the scientific investigation of commercial projects like cod-liver oil manufacture, dried-fish processing, canning, fish meals, soaps and glues, were included in a comprehensive programme of scientific investigations. These led to the submission of recommendations on the regulation of fisheries, the compilation of fishery statistics, the standardization of commercial processes, and marketing, which, in six crowded years, besides bearing eloquent tribute to THOMPSON's remarkable energy, foresight, and pioneering ability, clearly marked him as among the ablest of fishery research directors of his time.

In 1937, the scene for THOMPSON changed when he accepted the

invitation of the Commonwealth Scientific and Industrial Research Organization (C.S.I.R.O.) to found and direct a fisheries research organization in Australia. Before war for the second time interrupted his progressive scientific activities, THOMPSON had securely established the Fisheries Division of the C.S.I.R.O., had set up its research laboratory at Cronulla, near Sydney, N.S.W., and again, with an excellent team of workers, had successfully launched and in part prosecuted a research programme of abundant promise. War, of course, halted many of the advances he had planned, but from 1943 to 1946, while retaining his position as Chief of the Fisheries Division, THOMPSON rendered valuable service in his appointment as Comptroller of Fisheries in the Commonwealth Department of War Organization of Industry, charged with rationalization of the fishing industry in consonance with a policy of maximum production with minimum expenditure of manpower, fuel, and other capital war assets. He resumed his full responsibility as Chief of the Fisheries Division in 1946 and, in the words of another writer, "guided it to its present high position as one of the leading laboratories of its kind in the world".

Acknowledgement has been made elsewhere of the tangible benefits to Australian fisheries accruing from research under THOMPSON's vigorous leadership; in the establishment, for instance, and extension of whale, tuna, crayfish, and shark fisheries, together with exposition of the wisdom of relaxing fishing pressure on certain species, this to be offset by new fisheries suggested by his investigations. Nor, although doubtless for the most part beset by administrative problems, did THOMPSON forget an old love as the publication of at least two papers on the pelagic tunicates of Australia shows. But the titles, with their dates:—

"Investigation of the fishery resources of the Australian Commonwealth" (1939),

"Some conclusions reached during the quinquennium 1938–1943" (1943),

"Fish welfare" (1947), and

"Latent fishery resources and means of their development" (1950),

are in themselves clear and eloquent testimony of THOMPSON's work and policy in the discharge of a high and, by the nature of the work, difficult office. To a man of his forceful energy and forward outlook, the realization of failing health in the post-war years, with its inevitable retardation of the tempo of his working life, before he had had time to consolidate, as he would have wished, the fruits of his labours, and to savour more fully of their widespread recognition, must have come as a sore disappointment, as did, subsequently, his slightly premature retirement in 1954. There can be no question, however, that in the organizations he so rapidly and successfully founded, established, and

left so well-fitted to carry on his work, THOMPSON has a memorial than which there could scarcely be one more appropriate to the man he was.

THOMPSON attended, as an expert, the annual meetings of the International Council for the Exploration of the Sea in 1928, 1929, and 1930, and between 1926 and 1938 contributed a number of reports, on North Sea and Iceland haddock, West Atlantic cod, and other matters, which are to be found in the Council's *Rapports et Procès-Verbaux*. It was a singular pleasure to all his friends of these earlier years to welcome him again to the Council's meetings as an observer, first in 1949 and again in 1952. Likewise, his colleagues and friends took pride as well as pleasure in the announcement of the award to him in 1956, by His Majesty the King of Denmark, of the Silver Medal "Galathea", 1950–52, "in recognition of valuable service rendered to the Danish "Galathea" Expedition during the ship's visit to Australia in 1951".

Harold THOMPSON died in Edinburgh on 29. May 1957, on the eve of his impending return to Australia. To his widow and son we extend deep sympathy in the loss of a husband and father who, as a colleague, to some of us one of long standing, will ever be remembered with respect, admiration, and affection, for his qualities of alert and keen mind, his critical and forthright, but always helpful, judgement, his capacity for work and play and, stemming from the latter, his robust friendship.

J. B. Tait

Louis Lambert
1886—1957

Louis Lambert a succombé le 27 juillet 1957, après avoir consacré son activité à la conchyliculture française qu'il fit bénéficier de son savoir et de ses efforts.

Né à Cassel le 19 mai 1886, licencié ès-sciences et docteur en pharmacie des Facultés de Lille, Louis Lambert est entré à l'Institut des Pêches en 1923 avec le titre d'Inspecteur, il fut successivement nommé Inspecteur principal en 1928 puis Inspecteur général en 1933. Jusqu'à sa retraite en 1951, il dirigea avec maîtrise le Service de Contrôle de la Salubrité des Coquillages.

Sa compétence était grande et nombreux sont les professionnels qui purent apprécier la valeur pratique de ses conseils et de ses recommandations.

Il procéda notamment à des observations systématiques sur les divers gisements coquilliers des côtes de France et sur les techniques ostréicoles et mytilicoles les mieux appropriées aux différentes conditions naturelles.

Dans des missions à l'étranger, il recueillit d'utiles éléments de comparaison. Il participa à de nombreuses réunions internationales et fut à plusieurs reprises expert au Conseil International pour l'Exploration de la Mer.

Personnellement ou avec l'aide de ses collaborateurs, il s'attacha à la détermination topographique des causes possibles de contamination des eaux conchylicoles. Son action persévérante provoqua la réduction ou même la disparition complète de nombreuses sources de pollution; elle contribua efficacement à l'amélioration de la qualité sanitaire des huîtres et autres coquillages.

Il joua un rôle essentiel dans l'élaboration et la mise en application du décret du 20 août 1939 qui étendit l'exercice du contrôle sanitaire à tous les coquillages.

De nombreuses publications jalonnent la carrière de Louis LAMBERT. Citons principalement, en plus d'une monographie complète de l'ostréiculture dans les diverses régions de France, une série d'études sur la biologie et la reproduction des mollusques, leur valeur alimentaire et leur salubrité.

La conduite militaire de Louis LAMBERT est digne d'une mention particulière: il combattit brillamment lors de la première guerre mondiale, fit partie de l'armée d'Orient et fut promu Commandant.

Plusieurs décorations civiles et militaires vinrent récompenser ses mérites; il était notamment Officier de la Légion d'Honneur, du Mérite Maritime et de la Santé Publique.

Maurice Boury

A Note on the Use of the Nansen-Pettersson Water-Bottle

By

A. J. Lee and **G. C. Baxter,**
Fisheries Laboratory, Lowestoft

In the United Kingdom the Nansen-Pettersson insulated water-bottle is commonly used for determining the temperature and collecting water samples below the surface in shallow seas. The instrument as originally designed is described by EKMAN (1905). It consisted of five concentric cylinders; from the centre outwards they were of celluloid, brass, celluloid, brass, and brass, and the outermost cylinder was covered with ebonite on the outside. The four inner cylinders were connected by spacing pieces made of ebonite. The lid and bottom of the bottle consisted of brass and each had three india-rubber plates on the inside. These plates were strengthened by tinned brass disks and were joined together by ebonite spacing pieces. The cylinders and rubber plates were attached in such a way as to avoid continuous metallic connexion between the central chamber and the water surrounding the bottle.

The insulating properties of this bottle were investigated experimentally by EKMAN. He found that an increase of temperature outside the bottle of 1°C. caused the thermometer in the central chamber to rise 0·02°C. in 15 minutes, while an increase of 11°C. outside caused the thermometer to rise 0·02°C. in 9 minutes. In all the tests the thermometer reading remained very nearly constant for a certain time and then began to change rapidly. EKMAN showed that this was in accordance with the mathematical solution of the problem of the flow of heat through solid walls. He regarded the insulation as being effective for 8–9 minutes.

The insulated bottle at present used in British laboratories differs from that described by EKMAN. An account of it is given in an Admiralty publication (1932). It consists of six brass concentric cylinders connected by ebonite spacing pieces, the outermost cylinder being chromium-plated and the two innermost silver-plated. The lid and bottom are made of brass and are chromium-plated, and on the inside each carries a disk of ebonite sandwiched between two rubber washers. This form of insulation is said to prevent any changes of temperature for 6 minutes but no details of any tests are given.

In order to obtain more precise information about the present insulated bottle a series of tests has recently been carried out at the Fisheries Laboratory,

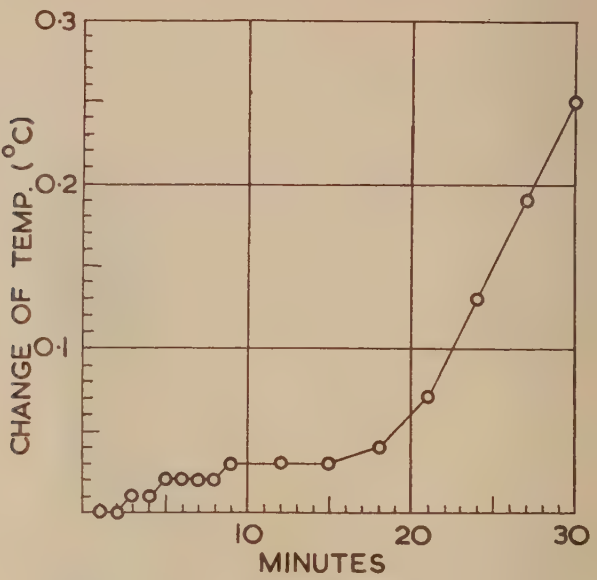


Figure 1. Change of temperature in the central chamber.
Outside temperature = 20·1°C.; initial inside temperature = 6·97°C.

Lowestoft. An open bottle was immersed in a tub of water and closed after 5 minutes. It was then removed from the tub and secured in the vertical position in a rack. The thermometer in the central chamber was read 1 minute after the bottle had been removed from the tub and then at regular intervals. The air temperature was obtained from two thermometers fixed to the rack on either side of the bottle. This test was carried out eight times, the difference between the air temperature and the water temperature being different on each occasion and varying between 4° and 13°C. The thermometers were all read at a range of two feet by means of binoculars fitted in a stand built to the pattern of those used at the National Physical Laboratory, Teddington.

Figure 1 shows the results of one of these tests in which the temperature outside the bottle was 13°C. greater than the water temperature. The left-hand end of the curve corresponds to the time when the bottle was removed from the tub. The curve shows that the insulation started to break down rapidly after 15 minutes. The other tests showed that when the temperature outside was 10°C. greater, the insulation started to break down rapidly after about the same length of time, and when it was about 6°C. greater, the thermometer in the central chamber did not rise more than 0·02°C. in rather less than 30 minutes. All the curves obtained show that small changes took place some time before the thermometer began to change rapidly. For example, in Figure 1, when the outside temperature was 13°C. greater than the water temperature, the thermometer in the central chamber had risen by 0·02°C. after 5 minutes and by 0·03°C. after 9 minutes. These changes might be due to the change of temperature of the mercury thread outside the bottle when it is moved from

the water into the air. The formula for the stem exposure correction is $Kn(t - t_s)$ °C., where K is the coefficient of cubical expansion of mercury relative to glass, n is the length of the exposed column, t is the temperature to be measured, and t_s is the mean temperature of the exposed column. In the case of Figure 1, $K = 0{\cdot}00016$, $n = 14{\cdot}3°$, and $(t - t_s) = -13{\cdot}1°$ if the two thermometers mounted on the rack on either side of the bottle are regarded as giving a close approximation to the mean temperature of the exposed column. Thus the stem exposure correction is −0·03°C. and it can be seen from Figure 1 that the thermometer in the central chamber started to rise after 2 minutes, had risen by 0·03°C. after 9 minutes, and then remained constant for 6 minutes until the insulation started to break down. As a check on the length of the time-lag that occurs before the error due to stem exposure becomes apparent, the thermometer was immersed in a mixture of finely-shaved pure ice and distilled water in a well lagged ice-bath and allowed to reach its ice point. The thermometer was then raised to partial immersion in a mean air temperature of 13°C. with the level of immersion the same as that experienced when the thermometer is in the water-bottle. The thermometer was read immediately and then afterwards at intervals of 1 minute. It was found that the thermometer rose by an amount equal to the stem exposure error in 5 minutes and then remained steady.

Ekman (loc. cit.) obtained from theoretical considerations the time during which the wall insulation is effective as:—

$$t = \frac{\varrho c b^2}{\pi^2 k}$$

where ϱ, c, k, and b are the specific gravity, specific heat, thermal conductivity, and thickness of the wall respectively. Considering the present form of bottle as being insulated by the water trapped between the concentric cylinders, we obtain $t = 11$ minutes. It is possible that heat may also be transferred by circulation of water in the insulating layer, but Ekman showed experimentally that it is not of a significant amount if the water layers are less than 5 mm. thick, as all but one are in our case. Similarly for the disks of ebonite on the lid and bottom we obtain $t = 12$ minutes and the presence of the thick rubber washers will lengthen this time. It would therefore appear on theoretical grounds that the insulation of the bottle should start to break down after about 11 minutes, but our experiments show that the thermometer reading is not affected by the breakdown until after 15 minutes. The lag is presumably due to the time taken for heat to be transferred through the central chamber.

When the difference of temperature between the inside and outside of the bottle was great, Ekman obtained changes of 0·01°C. after 2 or 3 minutes during his tests and the thermometer then stayed constant for several minutes. He suggested that these small changes were due to the exposed stem, but he does not appear to have carried out tests to see if this was so. He also assumed that the mercury thread took several minutes to take up even approximately the air temperature. Our results show that with the thermometers at present in use this is not so. In fact the efficiency of the insulated water-bottle as a means of obtaining temperatures at shallow depths seems to depend on the time in which the mercury thread begins to be affected by the temperature outside rather than on the insulation around the central chamber. With the outside temperature differing from the sample temperature by more than 10°C.,

if temperatures are required with an accuracy of $\pm 0{\cdot}01°C.$, the thermometer must be read within 2 minutes; if an accuracy of $\pm 0{\cdot}02°C.$ is required the thermometer must be read within 4 minutes. For smaller differences between the outside and inside temperatures the interval in which it is safe to read the thermometer becomes longer, and when the difference is less than 6°C. the thermometer does not change more than $0{\cdot}01°C.$ in under 19 minutes.

Summary

The insulating properties of the present British type of Nansen-Pettersson water-bottle have been examined. It is found that the efficiency of the bottle depends upon the time in which the exposed part of the mercury thread of the thermometer begins to be affected by the temperature outside, rather than upon the insulation around the central chamber.

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Statistical Tests for Significance Applicable to Distributions in Space

By

H. J. Buchanan-Wollaston

Part 1. Methods and Examples

Introduction

The methods described here are applicable in testing for the significance of calculated residual or resultant currents or calculated residual winds. They are also useful for determining whether migrations of marked fish or other organisms indicate a unidirectional tendency — a significant preference for migration in any particular direction, or a significant deviation from an equal tendency to migrate in all directions. Among other applications of the methods are testing for significance of bias in dice and in other devices used in games of chance. They are applicable equally to two- or three-dimensional distributions in space, and may be extended to include further dimensions, should such be found to have practical applications. The methods themselves are easy to understand and apply, but since parts of the theory on which they are founded are not quite so easy for non-mathematicians to understand, they are dealt with in Part 2 of the paper.

Since the purpose of this paper is the explanation of practical tests, no great accuracy in the calculations themselves has been aimed at, mainly because a mechanical calculating machine has not been available and the necessary calculations have had to be made through the medium of 4-figure logarithms and other tables. The results of the calculations are quite accurate enough for their purpose.

Theoretical basis of tests

The fundamental distribution on which the tests are founded is the multinomial, of which the simplest example is the binomial distribution. This is so well known in all its applications that it is not dealt with here. The more important tests depend on the 4-nomial.

Let us suppose that from a small fish-marking experiment 12 fish have been recaught and that the numbers taken in four quadrants centred on North, East, South, and West were 4, 0, 3, and 5, respectively.

We may wish to know first whether the observed inequality in allocation of numbers into the four sectors could reasonably be ascribed to chance. We therefore formulate the "null hypothesis" that the probability of the allocation is a term of the 4-nomial,

$$(\tfrac{1}{4} + \tfrac{1}{4} + \tfrac{1}{4} + \tfrac{1}{4})^{12},$$

which is the distribution expressing the hypothesis that each fish is equally likely to be in any one of the four sectors. Now it is quite easy to calculate the value of the term and indeed of all the terms of the 4-nomial, if n, the index number outside the bracket, be small. In the case of the symmetrical 4-nomial, however, it may be shown that the χ^2 distribution, with 3 degrees of freedom, supplies a test for significance of inequality in allocation sufficiently accurate for most practical purposes, even when n is only equal to 9. The test is carried out as shown in Table 1.

Table 1

	N.	E.	S.	W.
Expected	3	3	3	3
Observed	4	0	3	5
Difference	1	3	0	2

$$\chi^2 = \frac{1^2 + 3^2 + 2^2}{3} = \frac{14}{3} = 4{\cdot}6 \qquad (1)$$

From Table III of FISHER (1954) or from some other χ^2 table the value of P is found to be approximately 0·2. Inequality of allocation would not therefore be considered significant if the generally adopted criterion, $P = 0{\cdot}05$, be adopted.

It is generally more important to investigate whether there is a unidirectional tendency in migration of the fish than it is to enquire whether there is a significant deviation from equality in allocation. For this we must regard the test as being applied to vector quantities; this is quite allowable, since the fish have moved from the centre of marking and have not been placed in the sectors. If the actual distance travelled by each fish be disregarded, each represents a unit vector and we shall assume that each unit vector has a direction exactly towards one of the cardinal points, North, East, South, or West. The distribution giving the exact test of significance required is discussed in Part 2. The approximate χ^2 test, which is shown in Part 2 to be accurate enough for all practical purposes, is very simple to apply, the value of χ^2 being calculated by squaring the differences between opposite numbers in the allocation, summing the squares, and dividing the sum by half the number of observations (number of fish in the present case). Thus we have

$$\chi^2 = \frac{(4-3)^2 + (5-0)^2}{6} = 4{\cdot}3 \qquad (2)$$

There are 2 degrees of freedom and from Table III of FISHER the value of P is found to lie between 0·1 and 0·2. Unidirectional tendency is therefore not significant.

To complete the analysis of χ^2 we have what may be called balanced deviation from equality in directional tendency. For the test for significance of this type of deviation in the present case we have, for 1 degree of freedom,

$$\chi^2 = \frac{[(4 + 3) - (5 + 0)]^2}{12} = 0{\cdot}3 \qquad (3)$$

This is not nearly significant.

Summing the two components of χ^2 we have

$$4{\cdot}3 + 0{\cdot}3 = 4{\cdot}6, \text{ the total value of } \chi^2.$$

With only four basic directions or classes no other kind of deviation is possible. Any value of χ^2 in (2) is the square of a "normal" radius vector in two dimensions, having unit standard deviation in each dimension. The radius vector may be considered as a straight line from the centre of the base of a two-dimensional normal surface to any point on a circle about the centre, all ordinates erected vertically from this circle having the same height. The test at (2) is thus for the significance of any radius vector having the same length as that observed.

Of course, by disregarding distances travelled by the fish we are throwing away an important part of the information contained in our data. As is explained, however, in Part 2, it is probably allowable to employ as the fundamental distribution of the test, not the true 4-nomial, but a continuous distribution in which the frequencies need not be integral but must add up to the total number of observations. For instance, let us consider the hypothetical allocation, North 25, East 100·5, South 8·5, West 10, in which total distances travelled by 12 fish in each direction are shown. To reduce the total number to number of "observations" (fish in this case) each subtotal is divided by the mean distance, which is equal to 12. We have therefore this allocation of numbers of means:— North, 2·083; East, 8·373; South, 0·7125; West, 0·8333.

$$\chi^2 = \frac{(8{\cdot}373 - {\cdot}8333)^2 + (2{\cdot}083 - {\cdot}7125)^2}{6}$$

The value of P is equal to 9·8 approximately. This is beyond the range of the χ^2 table and high significance is shown. The value of χ^2 for balanced deviation is given by

$$\frac{[(8{\cdot}373 + {\cdot}8333) - (2{\cdot}083 + {\cdot}7125)]^2}{12} = 3{\cdot}425$$

The value of P lies between 0·05 and 0·1. This is not quite significant for 1 degree of freedom.

There may be a doubt whether the use of the number of means as a frequency of occurrence is justifiable in all cases; each case must be judged on its merits. There is certainly nothing unsound in applying the χ^2 distribution to a set of non-integral "frequencies", since the χ^2 distribution is continuous. True, it is not limited in one direction but is generally applied as an approximation to the true multinomial, which is limited in both directions.

Reverting to the question of balanced deviation, we may consider this allocation of unit vectors:— North, 28; East, 9; South, 32; West, 1.

$$\chi^2 = \frac{[(32 + 28) - (9 + 1)]^2}{70} = 35 \text{ plus}$$

This is far beyond the range of the χ^2 table. In such a case the null hypothesis of equality in direction is no longer tenable. The basic distribution is not a symmetrical 4-nomial but one in which the expected values at North and South are very much greater than those for East and West. On the expectation of equality in expected values,

$$\chi^2 = \frac{(32 - 28)^2 + (9 - 1)^2}{35} = 2{\cdot}286$$

The value of P lies between 0·1 and 0·2, i.e., not significant. To make allowance for inequality in expectation we take the expected values on the North and South lines as 30 and those on the East and West lines as 5 each. The null hypothesis now is that although the expectations on the two lines are unequal, yet on each line the expectation in one direction is equal to that in the opposite direction. We have therefore, for the new value of χ^2,

$$\chi^2 = \frac{(32 - 28)^2}{60} + \frac{(9 - 1)^2}{10} = 6{\cdot}67$$

The value of P is less than 0·05 and the residual or resultant would be considered significant now that allowance has been made for balanced deviation. This allowance is very important when dealing with sea currents near the shore or between sandbanks, since the tidal stream is much stronger along a channel than across it. The allowance is also important in dealing with fish-marking experiments near shore or in narrow channels.

If the exact value of P for any value of χ^2 for 2 degrees of freedom be required, it is easily calculated, since in that case $P = e^{-\frac{1}{2}\chi^2}$.

Even if two residual vectors be found not to be significant, there may yet be a significant difference between them, particularly if their directions are opposite to each other or otherwise very different from each other. For instance, in (2), the residual vector has a value of 5·1 approximately and the difference between this and an equal vector in the opposite direction is 10·2. On the assumption that the value of each vector was calculated from 12 observations, the variance of each is 6 and the variance of their difference is 12. On dividing the square of 10·2 by the variance, the value of χ^2 is found to be 8·67, P is less than 0·02, and significance is shown. A similar method of testing for the significance of the difference between two residual vectors in a case in which the directions of the vectors are not opposite to each other is dealt with later in this paper.

If one or both of the vectors compared be found on test to be significant, this implies that the assumption that they are, each of them, due to chance variations from a distribution defined by the null hypothesis is not acceptable. In that case, to apply a test for significance based on the acceptance of that hypothesis would be quite unsound and a method must be employed for the test quite different from that described. Such cases are not dealt with in this paper.

A very simple case of the application of the tests described to a three-dimensional allocation is dealt with in the next section, which is devoted to practical application of the tests to actual data.

Practical Applications

Current measurements

A great many determinations of residual drift or resultant current have been made from data obtained by means of CARRUTHERS' Drift Indicator. This works on the same principle as the well known Ekman current-meter but can be used for a much longer period than can that instrument. A large supply of metal balls of the same size as fairly small shot are contained in a hopper. A rotating vane is actuated by the current and after a particular number of rotations of the vane, a ball is dropped on to the centre of a grooved compass needle; the ball then runs along the groove and falls into one or other of sixteen sectorial compartments on a circular base which forms a part of the meter, the compartment into which the ball drops depending on the direction of the current. If the ball falls into compartment No. 1 in Figure 1 the current is running in a direction within $11\frac{1}{4}°$ of North on either side, since the compartments have an angular width of $22\frac{1}{2}°$. Each ball represents a true "unit vector", since its fall is the result of a given flow of water in a particular direction. The Drift Indicator, if used continuously over one or more tidal periods, gives an estimate of residual drift applying to the whole period of use on the assumption that every part of the whole body of water sampled by the meter at all times included in the whole period is moving in the same direction and at the same speed each time a ball is dropped. The fact that this assumption is rarely or never justified supplies an important element of "chance". This, combined with chance elements due to turbulence, to swinging of the ship from which the meter is used, to jerking of the meter in a seaway, to temporary jamming of the metal balls in the mouth of the hopper, and so on, makes it very necessary to grasp the fact that the recorded drift is a variable quantity and that at least a part of it is not real. If its recorded value be small, it is entirely possible that the whole of it is due to chance variation. The null hypothesis tested for acceptance is that the recorded drift is entirely due to chance elements.

Figure 1 shows the number of balls in each compartment of the Drift Indicator after a trial lasting for 6 complete tidal periods, the trial having been made from the "Cromer Knoll" lightship in July 1936 at a depth of 6 fathoms. The total number of balls dropped was 1470. If we wish to determine whether there is a significant deviation from equality in the allocation of the balls into the sectors, the required test is carried out by a method similar to that shown in Table 1. There are 15 degrees of freedom for χ^2 and the expected number of balls in each sector is $^1/_{16}$ of 1470, i. e., 91·875. This kind of deviation from expected values is not generally of much practical interest. The test for significance of residual drift is very simple if the null hypothesis under test is that any ball, randomly selected with regard to time, is equally likely to fall into any sector: for convenience, we may call this "circular" theory. The difference between each pair of opposite numbers is resolved into two components at right angles to each other, with, for instance, North as zero angle. The algebraic sum of the components in each dimension is found. Each total component is squared and the squares added together and divided by half the total number of balls dropped to give the value of χ^2. The resulting equation has therefore the same form as that given at (2) above. For the data shown in Figure 1 the total North component of the differences is $+3·79$ and the total East component

Figure 1. Diagram from record made by CARRUTHERS' Drift Indicator showing in outer ring, sectors of the circular base and, in inner ring, number of balls dropped into each sector.

+ 45·66, but since these are squared, their sign is irrelevant. We have therefore

$$\chi^2 = \frac{(45{\cdot}66)^2 + (3{\cdot}79)^2}{735} = \frac{2099}{735} = 2{\cdot}856$$

The value of P from FISHER's Table III lies between 0·2 and 0·3.

The theoretical basis of the test is as follows. The number of balls in each sector is assumed to be normally distributed with mean and variance each equal to the expected number, 91·875. The difference between any two opposite numbers has therefore variance equal to 183·75 and is normally distributed about zero. If the difference be divided by the square root of its variance, it becomes a value of χ, which is a signless normal deviate with unit standard deviation. In resolving such a deviate into North and East components it is multiplied respectively by cos. θ and sin. θ, where θ is the angle between the deviate and North. The standard deviations of the North and East components are also multiplied respectively by cos. θ and sin. θ, and the variances of these components are therefore multiplied respectively by $\cos.^2\theta$ and $\sin.^2\theta$. Variances are additive if they apply to the same dimension, so the variances of the components of the individual differences in either dimension may be added together to give the variance of the total in that dimension. Since the sum of m values of either $\cos.^2\theta$ or $\sin.^2\theta$ is equal to $0{\cdot}5m$ if m be even, and the values of θ are equidifferent and summed over a semicircle, the variance of each total component is equal to half the total number of balls dropped. Each

component of the residual drift expressed in terms of number of balls dropped, squared and divided by its variance, is a value of χ^2 having 1 degree of freedom, and these values may be added together as ordinary fractions having the same denominator to give the value of χ^2 having 2 degrees of freedom, χ^2 being in this case the square of a normal radius vector in two dimensions. The test is thus for the significance of a residual drift equal in strength to that observed but which may be in any direction. The amount of water flow represented by the fall of a ball is irrelevant in the test.

The value of P corresponding to the value of χ^2 found shows that the residual drift does not appear to be nearly significant if tested on "circular" theory. It is quite obvious, however, at a mere glance at Figure 1 that "circular" theory is unacceptable and that allowance must be made for symmetrically balanced or "elliptical" deviation, since the currents on a line roughly North-West and South-East are very much stronger than along the line South-West and North-East. Though in the test by circular theory it makes no difference which two lines at right angles to each other are chosen as axes, yet when non-circular or "elliptical" theory (see Pt. 2 p. 172) is applied, the choice of axes makes a very great difference. Assuming that N.W. be chosen as zero angle we have the following resolution of differences into components:—

N.W.		S.W.	
+ 24 cos. 0°	= +24	+ 24 sin. 0°	= 0
— 93 cos. 22½°	= —85·92	— 93 sin. 22½°	= —35·58
— 8 cos. 45°	= — 5·66	— 8 sin. 45°	= — 5·66
+ 5 cos. 67½°	= + 1·91	+ 5 sin. 67½°	= + 4·61
+ 2 cos. 90°	= 0	+ 2 sin. 90°	= + 2
+ 5 cos. 112½°	= — 1·914	+ 5 sin. 112½°	= + 4·609
+ 26 cos. 135°	= —18·39	+ 26 sin. 135°	= +18·39
— 61 cos. 157½°	= +56·35	— 61 sin. 157½°	= —23·34
	—29·62		—34·97

$(29{\cdot}62)^2 + (34{\cdot}97)^2 = 2099$, equal to the value obtained by resolution about the lines N.-S. and E.-W. In applying "elliptical" theory, however, the null hypothesis is *not* that the chance of a randomly selected ball falling into any sector is equal for all sectors but that though a ball is much more likely to fall into some sectors than into others, yet the chance, for each pair of sectors, that it should fall into one member of the pair is equal to the chance that it should fall into the opposite member. The variance of a difference is not now the same for all as it was when "circular" theory was applied, but is equal to the sum of the numbers of balls dropped which give the difference. It is necessary therefore to analyse these different variances into components. The sum of these components in one dimension will be found to be very different from that applicable to the other dimension. The analysis is as follows:—

N.W.		S.W.	
764 cos.² 0°	= 764	764 sin.² 0°	= 0
223 cos.² 22½°	= 190·3	223 sin.² 22½°	= 32·65
26 cos.² 45°	= 13	26 sin.² 45°	= 13
7 cos.² 67½°	= 1·03	7 sin.² 67½°	= 5·98
12 cos.² 90°	= 0	12 sin.² 90°	= 12
11 cos.² 112½°	= 1·611	11 sin.² 112½°	= 9·39
46 cos.² 135°	= 23	46 sin.² 135°	= 23
381 cos.² 157½	= 325·2	381 sin.² 157½	= 55·8
	1318		152

The sum of the two component variances is equal to 1470, the total number of balls.

$$\chi^2 = \frac{(29{\cdot}62)^2}{1318} + \frac{(34{\cdot}97)^2}{152} = 8{\cdot}712$$

The value of P now lies between 0·01 and 0·02 and the residual drift is shown to be significant. Significance is entirely due to the component across the line of the tide, the value of χ^2 for the residual component along this line being only 0·6658. The significance of the cross-drift was obscured, when "circular" theory was applied, by the assumption that a given variation in a very strong or very long-lasting current is as significant as the same variation in a very weak or short-period current. The value of χ^2 for the cross-drift is 8·046. The corresponding value of P, for 1 degree of freedom, is a long way outside the range of FISHER's Table III.

The value of χ^2 for "elliptical" deviation is equal to

$$\frac{(1318 - 152)^2}{1470}, \text{ i. e., } \frac{(1166)^2}{1470}$$

The value is so high that it is not worth while carrying out the division.

If it is required to apply a significance test to the difference between two residual drifts given by the Drift Indicator, the square of the difference between the components in each dimension is divided by the sum of the variances applying to these components and the results added together to give the required value of χ^2 with 2 degrees of freedom. It is only applicable if neither residual drift proves significant under test.

There are several other types of current-meter, differing in principles of action from the Drift Indicator, which give results quite as suitable for the application of tests for significance of residual drift as are those from the Drift Indicator.

The tests described depend on the number of separate "observations". They may be applied to the results from meters which give continuous records of both speed and direction. Such records are infinitesimally divisible and any grouping which gives suitable numbers of unit vectors may be adopted.

The larger the number of independent observations or trials in an experiment the greater the chance that a small but real deviation from expectation will prove, under test, to be significant.

Residual currents calculated by the British Meteorological Office

These are calculated from comparison between the expected position of a ship deduced from a daily run on a known course and speed and the astronomical "fix" at the finish of the run. The difference between these two results is taken as an estimate of residual current over, approximately, two tidal periods. Since each individual result is an estimate of resultant current over a period, tidal influence is eliminated and the null hypothesis that each calculated resultant current is equally likely to be in any direction is *a priori* acceptable and the simple "circular" theory is applicable in making tests of significance.

In addition to charts showing, by means of arrows of different lengths, the direction and strength of calculated resultant currents over wide sea areas, the Meteorological Office also publish for the same areas charts of "roses" or

diagrams of frequencies of resultant current directions grouped in 16 sectors of the circle. One such rose, namely No. 104, comprising 137 records applying to an area extending from 48° to 50°N. and from 6° to 10° W. and to the period February, March, and April, was analysed on "circular" theory, and undirectional tendency in frequency of directions was found to have no significance, the value of P lying between 0·5 and 0·7. Only data from the British Meteorological Office were included in the rose.

The total of the resultant currents in all directions recorded for the area and period covered by Rose 104, including 264 Dutch records and 7 zero currents, was 3627. The mean resultant current in all directions was thus 8·888 miles per day. On allotment of the directions and signs to the individual resultant currents, the North component of the total was found to be −184·7 and the East component +393·2. On dividing each component by the mean, to obtain the number of means or number of unit vectors in each, we have, in terms of number of means, North component equal to −26·16, East component equal to +44·24, and therefore

$$\chi^2 = \frac{(26{\cdot}16)^2 + (44{\cdot}24)^2}{204} = 12{\cdot}95$$

The value of P is much less than 0·01 and the resultant current is highly significant. When the Dutch data were omitted, the value of P was found to lie between 0·5 and 0·7 and therefore only the results from the Dutch data were significant.

"Elliptical" deviation from expectation was found to be quite insignificant, the value of P, for 1 degree of freedom, lying between 0·3 and 0·5.

Fish-marking experiments

Fish wandering at random from a centre, if there be no tendency to wander in any particular direction, will tend to be normally distributed about the centre. The distribution will be normal in each dimension and the variance of the distance travelled in any direction will be proportional to the number of "chances", for instance, days at liberty; the standard deviation therefore will be proportional to the square root of the number of days at liberty. Thus, if recaptures have been made after varying numbers of days since marking, the distance travelled by each fish should be divided by the square root of the number of days the fish was at liberty, before the test for significance of unidirectional tendency in migration is applied. The result will be in terms of miles per day.

If, in a fish-marking experiment, the number of recaptures is fairly large, say 20 or more, these are preferably grouped in 4, 8, or 16 sectors, according to the number involved, the methods already described being applied. If the number of recaptures be very small it is preferable not to group the data but to resolve them separately. Each return may be treated as a difference since any distance travelled by a fish in any direction is expected, on the appropriate null hypothesis, to be balanced by an equal distance in the opposite direction. What is "expected" is that half of each distance should be in one direction, the other half in the other direction. The variance of each is therefore equal to the distance itself. As an example, let us suppose that 9 fish have been recaptured after a varying number of days and that the total distance travelled

by them, after adjustment for time at liberty, has been 54 miles, the mean distance per day thus being 6 miles. The individual distances were as shown in Table 2.

Table 2

Direction	N.	N.20°E.	E.	S.30°E.	S.25°W.	S.50°W.	S.80°W.	N.70°W.	N.45°W.
Miles travelled ...	7	5	10	7	8	4	3	5	5

Resolving about North and East we find that the North component is approximately $+0{\cdot}545$, and the East component approximately $-2{\cdot}425$. On dividing these by the mean we have, for the North component, $+0{\cdot}091$ and for the East component, $-0{\cdot}404$. Since the angles of travel have not been equidifferent, the total variances in the two dimensions will not be equal to each other and these must be resolved into components, the same numbers being used as in Table 3, but without signs, and multiplied by the squares of the appropriate trigonometrical ratios instead of by their first powers. It will be found that the North component of the variance is 28·062 and the East component 25·938. Dividing these by 6 we have 4·677 and 4·323 respectively. Since these are nearly equal to one another, we may assume that "elliptical" deviation is not significant and apply "circular" theory. Thus we have

$$\chi^2 = \frac{(0{\cdot}091)^2 + (0{\cdot}404)^2}{4{\cdot}5}$$

Unidirectional tendency is therefore completely insignificant. It is possible, however, that if the axes for resolution had been other than North and East it would have been found that "elliptical" deviation should have been allowed for.

A three-dimensional example

In 54 actual throws of a cubical die the frequency with which each number occurred, in order from 1 to 6, was 4, 6, 11, 10, 14, and 9 respectively. The differences in frequency between opposite faces were thus 5, 8, and 1 respectively. The variance of each difference is equal to $\frac{1}{3}$ of the total number of throws. The value of χ^2 is exactly 5 and P for 3 degrees of freedom lies between 0·1 and 0·2.

Part 2. Mathematical Notes

The exact distribution of the resultant vector

The value of p for any resultant vector may be obtained by picking out from the appropriate multinomial all terms in which the numbers in the classes, a, b, c, and d give that vector and summing them. This is only practicable if n, the number of unit vectors involved, is small and even in that case the process is very tedious. The exact distribution has, however, been worked out for $n = 9$ divided into 4 classes. Table 3 shows the values of p and P for each resultant vector and the corresponding values for χ^2 with 2 degrees of freedom.

Agreement between the values of P is fairly good, in view of the small number of classes and small value of n, but significance is consistently overestimated by χ^2.

Table 3

Vector	1	2·236	3	3·606	4·123	5	5·385	6·083
p	0·2423	0·3230	0·1076	0·1385	0·0923	0·0544	0·0231	0·0099
P.....	1	0·7578	0·4348	0·3272	0·1887	0·0964	0·0420	0·0189
χ^2		1·111	2	2·889	3·778	5·555	6·445	8·409
P_{χ^2}		0·5757	0·3679	0·2358	0·1513	0·0621	0·0398	0·0149
Vector		6·403	6·708	7	7·280	8·062	9	
p		0·0038	0·0026	0·0012	0·0011	0·0003	0·00002	
P.....		0·0090	0·0052	0·0026	0·0014	0·0003	0·00002	
χ^2		10						
P_{χ^2}		0·0068						

The exact distribution of the difference between two resultant vectors

The distribution has been worked out for the case in which n is equal to 9 and the number of classes to 4 for each of the two vectors compared. Table 4 shows the value of P_{χ_2} and of P for all differences within the region of interest for testing purposes. The value of χ^2 is equal to the square of the vector difference divided by 9.

Table 4

Difference (d)	9·766	9·1	8·391	7·343	6·438	5·383	3·531	2·533
P	0·0043	0·0060	0·0179	0·0411	0·0835	0·179	0·4784	0·7305
P_{χ^2}	0·005	0.01	0·02	0·05	0·1	0·2	0·5	0·7

The values of P_d are not very exact owing to lack of facilities for exact calculation but the errors are small in proportion to the values themselves. The agreement between the two sets of values of P is sufficiently good to show that it is reasonable to use the test even when the number of classes and the value of n are quite small.

The "continuous multinomial"

The equation to this distribution may be put into mathematical form by substituting gamma-functions for the factorials in the coefficient term of the symmetrical multinomial and inserting a constant to be determined by integration. A random sample from a m-nomial approximating to this distribution, as applied in Part 1 of this paper, may be made by mixing together a very large number of beads comprising equal numbers of m different colours, drawing a sample of p beads from the pool, and recording the number of beads of each colour in p; n such samples should be drawn and the number of beads of each colour in each sample recorded, n being equal to the number of observations in an experiment. The total number of beads of each colour is then divided by p to give the number of means in each colour. The colours may correspond to directions of vector components. Sampling may be by random numbers instead of by beads. Values of χ^2 calculated from repeated sets of samples may be compared with the χ^2 distribution.

"Circular", "non-circular", and "elliptical" theories

These affect the calculation of the variance of a residual vector and therefore the calculated value of χ^2. According to "circular" theory the variance in each dimension is predetermined. According to general "non-circular" theory the variance in each dimension is calculated by resolving the sums of pairs of opposite vectors along two lines at right angles to each other and summing the components, the positions of the two lines being arbitrarily chosen without reference to the shape of a current or migration "rose". "Elliptical" theory is only applicable when the rose is obviously much more extended in both directions along one particular line than along the line at right angles to it. Application of this theory differs from that of general "non-circular" theory only that in the former the lines along which sums of expected values are resolved are not arbitrarily chosen but chosen so that they agree with the major and minor axes of the rose. If the rose be markedly eccentric but not suggestive of elliptical shape it is preferable to apply general "non-circular" rather than "circular" theory.

Summary

It is explained that the multinomial distribution and the normal approximation to it are applicable to frequencies of "unit vectors" which are classified according to their directions. A χ^2 test may therefore be applied to test for the acceptability of certain hypotheses, for instance, that marked fish are equally likely to migrate in any direction from a centre — when distances travelled by the fish are not taken into account. A two-dimensional χ^2 distribution may be derived from the approximation to the multinomial which provides a test for significance of unidirectional tendency in frequencies of "unit vectors". This is applied to frequencies of directions in migration of marked fish, to frequencies of current directions calculated by the British Meteorological Office and to currents calculated from current-meter data.

A continuous distribution is described which has affinity with the multinomial but in which "frequencies" may be non-integral. The approximation to a two-dimensional derivative from this provides a χ^2 test applicable to non-integral "frequencies" of unit vectors which are mean distances or velocities differing only in direction. Its application to a "rose" giving both directions and speeds of currents to test for the significance of the resultant current is described, as is also the analogous test for unidirectional tendency in migration of marked fish when account is taken of distances travelled by the fish.

The exact distribution of a resultant vector is compared with the approximate χ^2 distribution.

The "continuous multinomial" is given mathematical form and a method of sampling from a distribution approximating to it described.

Different theories affecting the calculation of χ^2 are discussed.

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Primary Production in the Arctic

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Introduction

While assisting Mr. J. CORLETT in his studies of sub-arctic plankton, I had the opportunity to work on the following problem, with encouragement from Dr. D. H. CUSHING, who has also very kindly revised this paper since I left the Fisheries Laboratory.

The production of phytoplankton in the western Barents Sea has two complementary components. The first is the fact that on the Bear Island bank, in arctic water, production starts in April, whereas in the deeper Atlantic water, production does not start until June (CORLETT, in preparation). The second is that as the ice recedes to the north-east, an outburst of phytoplankton takes place in its wake. An attempt will be made to account for both phenomena by SVERDRUP's theory of the interaction of the critical depth with that of the homogeneous layer (1953).

The Utilization of Energy in the Bear Island Area from February to June

First, the energy reaching the sea surface will be calculated; from this, the energy reaching the whole euphotic zone will be obtained and so the compensation depths and critical depths for the whole period can be calculated. By means of the relation between energy and the grammes of carbon produced per day per gramme of carbon of phytoplankton (g.C/day/g.C) given in RILEY, STOMMEL, and BUMPUS (1949), a theoretical algal reproductive rate will be derived.

The incident energy was calculated from the equation (MOSBY, 1932):—

$$I_0 = 0{\cdot}027\,(1 - 0{\cdot}075\,C)\,L \text{ g.cal./cm}^2\text{./min.},$$

where I_0 is the incident energy,

C is the mean cloudiness in the area as a fraction,

L is the mean altitude of the sun.

A constant (0·027) expresses the atmospheric turbidity at 70°N.; this value was derived from observations in the Arctic and so is very suitable for the

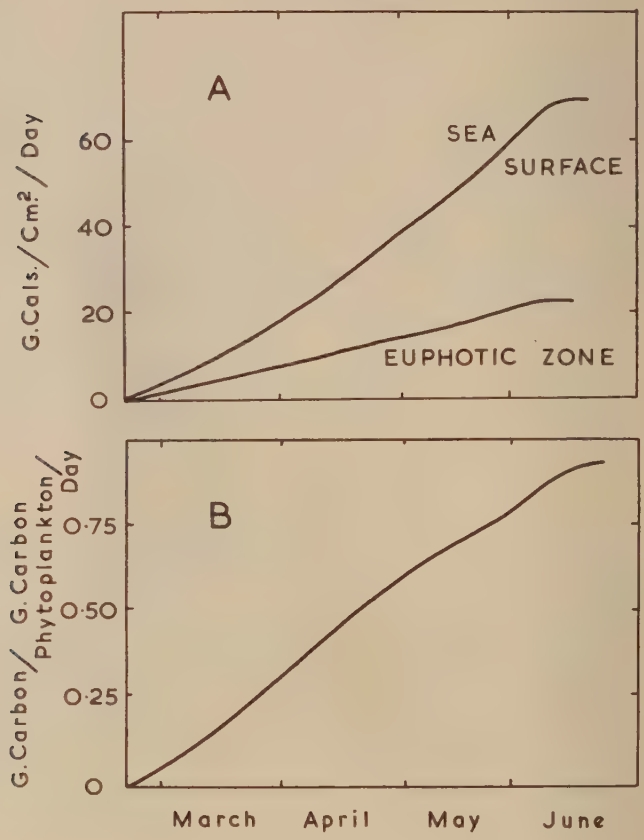

Figure 1, A. Energy available for photosynthesis during spring and early summer at Bear Island, 74°30′N., 19°E.
B. Reproductive rate of diatoms calculated from energy values in the euphotic zone (after JENKIN (1937) and RILEY *et al.* (1949)).

present purpose. The calculations were made in weekly periods, with the average cloud amounts observed at the meteorological station on Bear Island (Norsk Met. Årbok, 1953) and the mean altitudes of the sun in latitude 74°N. taken from the Nautical Almanac (1955).

For the first six months of the year 1953, the average cloudiness was greater than seven-tenths, so it was assumed that the average reflection loss at the sea surface was that from a totally overcast sky, namely, 9% (SVERDRUP *et al.*, 1942). A further factor is that only one-fifth of the incident energy is used by the algae in photosynthesis, the other four-fifths having been absorbed in the first few centimetres of water (SVERDRUP, 1953). The estimated values for incident energy corrected for reflection and absorption are shown in Figure 1 A.

The absorption of energy in the euphotic zone is given by:—

$$I_e = I_d e^{-kd},$$

where I_e is the energy penetrating the sea surface, after reflection and absorption losses have been taken into account, I_d is the energy reaching depth d, and k is the extinction coefficient.

The extinction coefficient for green light was measured by WIMPENNY and CORLETT (unpublished) in July 1953, and $k = 0{\cdot}065$ to $0{\cdot}100$. JENKIN (1937) has shown that the compensation depth, which defines the lower limit of the euphotic zone, may be given the value of 0·13 g.cal./cm.^{2}/hr. So, from average estimates of incident energy, the average quantity of energy reaching the euphotic zone can be calculated. These estimates are shown graphically in Figure 1 A.

SVERDRUP (1953) has defined a critical depth as:—

$$\frac{D_{cr}}{1 - e^{-kD_{cr}}} = \frac{\bar{I}_e}{I_c \cdot k},$$

$$\text{so} \qquad D_{cr} \simeq \frac{I_e}{I_c \cdot k},$$

where $\bar{I}_e$ is the average energy penetrating the sea surface, I_c is the energy at the compensation depth, and D_{cr} is the critical depth.

Similarly, the compensation depth, D_c, is defined by:—

$$D_c = \frac{1}{k} \log_e \frac{I_e}{I_c}$$

Figure 2 shows the critical depth and compensation depth calculated for the Bear Island area from February to June from the estimates given above. The importance of the critical depth in relation to the depth of the homogeneous layer is shown below.

Energy as g.cal./cm.^{2}/day has been related to the algal reproductive rate as g.C produced/day/g.C phytoplankton by RILEY *et al.* (1949) from the data of JENKIN (1937); the relation is linear up to 25 g.cal./cm.^{2}/day. The estimates of average energy reaching the euphotic zone can be used to make a graph of the average algal reproductive rate for the period February to June. This is shown in Figure 1 B.

A check on the estimated reproductive rate may be obtained by means of the ^{14}C technique. On 11. May 1954 in 75°15′N., 25°00′E., CORLETT (unpublished) found that 1·3 g.C/m.^{2}/day was produced (in water samples from 0, 5, 10, 20, 30, and 50 m., kept at 11,000 lux at 5·5°C. for three hours). The calculation was made by STEEMANN NIELSEN, in the "Dana" expedition to Greenland, 1954; a temperature correction of 5% per 1°C. was made and the depth of the euphotic zone was taken to be 40 m. The quantity of algae in the water-bottle samples was $6{\cdot}23 \times 10^9$ cells/m.^{2}; if the mean cell volume is taken as being a little below that of *Rhizosolenia alata* (12,000 μ^3 — CUSHING, 1955), the weight of the standing stock at this time was approximately 1·56 g.C/m.^{2} (the table of equivalents in SVERDRUP *et al.*, 1942, was used).

From Figure 1 B, the estimated algal reproductive rate is 0·63, so the production should be $1{\cdot}56 \times 0{\cdot}63 = 0{\cdot}98$ g.C/m.^{2}/day, which is to be compared with that observed from the ^{14}C method of 1·3 g.C/m.^{2}/day. The measure of agreement checks the estimated reproductive rate very well, when the number of approximations in each method are considered.

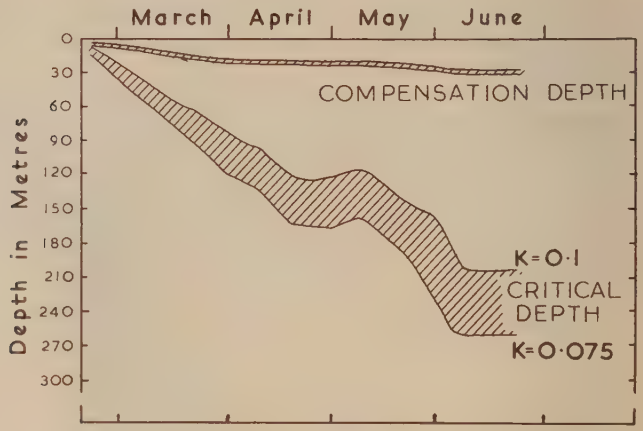

Figure 2. Critical depth and compensation depth near Bear Island in spring and early summer.

Stability in the Bear Island Area from February to June

Figure 2 shows the development of the compensation depth and the critical depth during spring. It may be recalled that the compensation depth is that depth at which the rate of photosynthesis equals the rate of respiration. The rate of photosynthesis is very much greater at shallower depths, but the rate of respiration is roughly the same as that at the compensation depth, when temperature differences are allowed for. The critical depth may be defined as that depth above which the total photosynthesis is equivalent to the total respiration, both beneath unit surface and for unit time. In practice, the critical depth is usually about nine times the compensation depth.

The critical depth was so named by SVERDRUP (1953) because if the depth of the homogeneous layer is greater than that of the critical depth, photosynthesis cannot be greater than respiration. If the algae are swept down to greater depths, the total photosynthesis in the water column cannot exceed the total algal respiration.

Table 1 shows a comparison of the depth of the homogeneous layer at arctic water stations and at Atlantic water stations (estimated by my colleague Mr. A. J. LEE) and the critical depth. Two points are immediately obvious; the first is that the critical depth exceeds the depth of the homogeneous layer in arctic water in March and April and this is when production begins. The second is that in the Atlantic water, the critical depth does not exceed the depth of the homogeneous layer until the end of May, and production does not start in the Atlantic water until May or June.

The depth of the homogeneous layer is less at the arctic water stations for two reasons:—

(1) some are shallow, i. e., depth of water less than the critical depth;
(2) melt water in March and April produces pycnoclines (or density gradients) from 10 to 25 m.

The reason why a wave of production follows the retreating ice edge across the Barents Sea in spring and early summer is that the reduction of the depth of the homogeneous layer is greatest close to the ice.

Table 1

Comparison of critical depth and the depth of the homogeneous layer in Arctic and Atlantic water

Months	Nov.–Feb.	March–April	May	June	July–Oct.
Critical depth	0·5 m.	30–140 m.	140–190 m.	190–240 m.	240–300 m.
Depth of homogeneous layer					
1. Arctic water stations.....	75 m.	50 m. (Melt water causes pycnoclines from 10 to 25 m.)	25 m.	25 m.	30–60 m.
2. Atlantic water stations.....	>200 m.	>200 m.	>150 m.	25–75 m.	40–80 m.

Discussion and Conclusions

Critical depths were estimated at a number of stations in arctic and Atlantic water in the Bear Island area. The same information was used to calculate a theoretical reproductive rate which compared quite closely with the observed one, with the ^{14}C technique. It is suggested that similar methods could be used to calculate algal reproductive rates elsewhere, because they are essential to any study of marine production, in which the effects of different factors are to be distinguished.

The comparison of critical depths with the depth of the homogeneous layer links the complementary phenomena in the Barents Sea, namely, the late production in the deep, warm Atlantic water and the early production close to the ice edge in the Barents Sea proper. A further examination of the wave of production following the retreating ice edge will appear in a paper by my colleagues Mr. A. J. Lee and Mr. J. Corlett.

Summary

Sverdrup's theory of the initiation of production has been used to describe the course of production in the Arctic in the early summer. The theory accounts for two phenomena, firstly, that production starts in April on the Bear Island bank and in June in the deeper Atlantic water and secondly that as the ice recedes to the north-east over the Central Bank, an outburst of phytoplankton takes place in its wake.

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The Balance between Phytoplankton and Zooplankton in the Sea

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Introduction

There is at present a keen interest in the study of marine plankton, the reason for which is the possibility of using more of the products of the sea as human food. Whether the plankton itself is considered a potential source of human food or whether the increase in food from the sea has to be met by the same organisms as today — primarily fish — it is of importance to understand the production of phytoplankton and the relationship between phytoplankton and zooplankton, the path by which the organic matter produced finally reaches the fish.

Rather different views about the problems connected with marine plankton have been expressed from time to time. Without in any way attempting to review the study of plankton as a whole we may here consider one particular problem. Let us focus our attention on the relationship between phyto- and zooplankton. Before discussions on this subject can begin, however, a number of minor points must be cleared up. If this is not done, there is little sense in discussing the main problem. These questions are:— How can (1) the phytoplankton and (2) the zooplankton be adequately collected and enumerated? (3) Is it possible to obtain by random samples representative estimates of the phyto- and zooplankton?

1. The standing crop of phytoplankton

Very few of the assessments of the standing crop of phytoplankton made in past years can be considered sufficiently reliable. Even normally reliable techniques may in certain circumstances give rather poor results. It is, however, not the aim of the present paper to discuss the different techniques for estimating the standing crop of phytoplankton. This was one of the main topics of the symposium on primary production held at Bergen in September 1957.

In the pioneering stage of plankton studies the fine bolting silk (No. 20 or No. 25) used for the nets was thought to be able to retain practically the whole bulk of plankton algae found in the sea. In 1908, however, LOHMANN showed irrefutably that net-caught samples gave very incomplete pictures of the quantity of phytoplankton present in the sea. A water sample may contain

very much phytoplankton while a fine-mesh net, used at the same time, might retain practically nothing.

Silk nets nevertheless continued to be used extensively in quantitative phytoplankton investigations, in spite of several further warnings (cf. STEEMANN NIELSEN, 1938; GESSNER, 1944). The introduction of the measurements of the chlorophyll present in net samples by KREPS and VERJBINSKAYA (1930) and others led to no improvements. The use of nets for obtaining samples from which to estimate the standing crop of phytoplankton has undoubtedly given rise to much confusion in the study of plankton.

2. The standing crop of zooplankton

The zooplankton is a very heterogeneous group. It must be admitted that a single method of sampling cannot produce adequate figures for all kinds of zooplankton. The first step in the investigation must be to determine which method is to be used. A large part of the quantitative work done on zooplankton was undertaken in connexion with investigations on the feeding of fish, above all the herring in European waters. The methods commonly used in zooplankton studies are thus especially adapted for quantitative capture of the organisms in which herring and other fish feed.

A Hensen net (No. 3 silk) thus seems to be excellent for estimating the quantity of adult *Calanus* present in the sea, this copepod being the principal food of the herring, at least in the North Sea. Quantitative determination of zooplankton with a net of No. 3 silk, however, may give quite misleading results when the inter-relationship between phyto- and zooplankton is being studied. An example of this is given below.

During the last war fairly intensive plankton studies were made in the Danish Isefjord in the course of which zooplankton samples were taken by two different techniques used simultaneously (cf. JESPERSEN, 1949). In a particular locality at which the depth of the water was 5 m., 8-L. water samples were collected at all seasons of the year from the surface and from 4 m. and filtered through No. 25 silk, which retains all metazoa. At the same time two vertical hauls with an open net (diameter 30 cm. No. 3 silk) were made from 4 m. to the surface. The counts from both types of plankton catches have been published by JESPERSEN (1949).

Table 1 shows the numbers of holoplankton animals estimated from the two 8-litre water samples (= 16 litres) on 23 days at various times of the year, expressed as percentages of the numbers in the two net samples. The volume of water filtered by the net during the two hauls was in all probability about 150 litres. If all zooplankton organisms had been taken in the same proportion by the two techniques, we should have expected the maximum percentage in Table 1 to be about 12. It is, however, in every instance higher, varying from 16 to 12,600. No. 3 silk is much too coarse to retain all zooplankton organisms. The copepod nauplii, which are usually present in by far the highest numbers, are evidently not retained at all by No. 3 silk.

Another example may be given. In a recent work on the Sargasso Sea, FISH's (1954) estimates of the numbers of zooplankton organisms present are only about 1 % of those made by HENTSCHEL (1937) for the corresponding eddy in the South Atlantic. The latter used the technique mentioned below, whereas FISH used a Clarke-Bumpus sampler (No. 2 silk bolting-cloth).

Table 1

The number of holoplanktonic animals in two 8-litre samples filtered through silk No. 25 as percentages of the numbers in net-caught samples (about 150 litres of water filtered through silk No. 3)

The measurements, which were made in three different years, arranged according to seasons.

Month	Day	Year	%	Month	Day	Year	%	Month	Day	Year	%
1	20	1943	42	5	28	1943	115	9	30	1941	23
2	12	1943	300	6	18	1943	410	10	14	1941	48
3	5	1943	39	7	8	1943	12,600	10	28	1941	123
3	26	1943	129	7	21	1942	54	11	19	1941	37
4	16	1943	35	7	30	1943	234	11	27	1942	27
4	23	1942	101	8	20	1943	1,450	12	10	1941	42
5	7	1943	16	8	25	1942	145	12	18	1942	43
5	19	1942	350	9	29	1942	175				

Although one of the smaller plankton animals not retained by No. 3 or No. 2 silk very likely eats considerably less phytoplankton per day than one of the larger specimens caught by the silk, at least some periods exist during which by far the major part of the phytoplankton is eaten by the zooplankton of the size not caught by the coarse silk. As the proportion between number of zooplankton organisms retained by the net and number not retained is highly variable, the relation between the phyto- and the zooplankton can hardly be adequately assessed when gear of such coarse silk as No. 3 or No. 2 is used for collecting the zooplankton.

What appeared to be an adequate method for sampling zooplankton in studies of the phytoplankton-zooplankton inter-relationship was introduced by LOHMANN (1908). Large water samples were drawn by a pump from different depths and filtered through the finest bolting silk. HENTSCHEL (1932, 1933) concentrated the plankton in 4-litre samples by sedimentation before counting. Several modifications of LOHMANN's technique have been put forward, but most of them involve the use of coarser silk, thereby missing one of the most essential parts of LOHMANN's technique. It is easy to understand why most zooplankton specialists have avoided the use of the finest bolting silk. The immense masses of phytoplankton often found — above all, the chains of *Chaetoceras* and other diatoms — may make counting the zooplankton very tiresome and slow.

If only limited time is available, it is preferable to count the relatively few zooplankton organisms present in the mass of phytoplankton obtained in the small water samples filtered through the finest bolting silk — or similar material — instead of counting the numerous zooplankton organisms in large water samples filtered through coarse silk and therefore free of phytoplankton. Water samples of only 4 litres would be considered *a priori* too small to represent the zooplankton in tropical and subtropical parts of the open ocean. This is of course true if the quality of the plankton has to be taken into account but — HENTSCHEL's investigations on the "Meteor" expedition showed that a reliable assessment of the total herbivorous zooplankton might be obtained in that way.

Larger water samples are necessary, however, if a more detailed picture of conditions in open waters is wanted. The 100-litre water-sampler equipped with a net of No. 25 silk — STEEMANN NIELSEN (1935, 1943) — may be

mentioned in this connexion. Nets of the finest bolting silk should also be applicable for this purpose if a flow-meter can be used and works satisfactorily in conjunction with No. 25 silk. An ordinary Clarke-Bumpus sampler (Clarke, 1940), which is made either of No. 2 silk (21 strands per cm.) or of No. 10 silk (43 strands per cm.), cannot be considered satisfactory for sampling all herbivores. Many copepod nauplii are not retained by No. 10 silk.

3. Patchiness of plankton

Somewhat divergent views are held about the possibility of obtaining representative assessments of the phyto- and the zooplankton by random samples. Localities with complicated and variable hydrographic conditions — for example, fronts between different water masses — must of course be excluded from consideration. In coastal areas considerable differences occur between the hydrographic conditions in neighbouring localities. The conditions for plankton production thus also vary.

On the other hand, large hydrographically uniform regions are to be found in the oceans. Investigations carried out in the Atlantic by the two German expeditions — the "Deutschland" in 1911 and the "Meteor" in 1925–27 — showed that different water masses — particularly those in the tropics and the subtropics — could be distinguished by the numbers of plankton organisms present as clearly as by their physical properties (cf. Lohmann, 1913, 1920; Hentschel, 1932, 1933–1936). This material was specially suitable for estimates of phytoplankton. Hentschel was able to show that both quantitatively and qualitatively the plankton is fairly uniform in the various parts of the ocean. It was of course not fitted for determinations of the qualitative composition of the zooplankton.

Lohmann's and Hentschel's assessments of the standing crop of phytoplankton in the oceans made by centrifuging the samples and counting the living algae have been corroborated in recent years by measurements of the production of organic matter by the phytoplankton made with the carbon-14 technique (cf. Steemann Nielsen, 1954; Steemann Nielsen and Aabye Jensen, 1957). The euphotic water masses in the different parts of the oceans may be adequately characterized by their capacity for producing organic matter. In regions with nearly the same hydrographical conditions the rates of production per unit of surface are also nearly the same. The production of phytoplankton in the oceans must in general be regarded as a steady-state process. The conditions in fairly high latitudes are of course influenced by seasonal changes. Seasonal changes may also be found in low latitudes, however, as for instance, in regions in which monsoons occur.

Violent storms may also sometimes give rise to exceptional hydrographic conditions, for instance, in some parts of the tropics in which water relatively rich in nutrients occurs not very far below the surface. After such storms, which may occur only at intervals of years, extraordinarily favourable conditions for the growth of plankton algae may be present for a time; this again affects the production of zooplankton (cf. Sette, 1955).

These instances, however, do not invalidate the general rule that a particular oceanic region is characterized by a fairly stable rate of primary organic production.

As mentioned above, the concentration of metazoa in a definite oceanic

area such as the South Atlantic Eddy was found by Hentschel (1933) to be fairly constant. This does not necessarily mean, however, that the population of metazoa does not change qualitatively. According to Fish (1954) there seems to be a fairly marked biological cycle in the Sargasso Sea. If a coarse net is employed, periods of relatively high (although absolutely low) zooplankton concentrations alternate with periods of low concentrations. As Fish mentions, no nauplii or early stages of the small copepods were caught. This suggests that during the periods when the numbers of animals taken by the coarse net were small, the main bulk of the zooplankton consisted of nauplii and early stages of copepods. It thus seems very likely that the fluctuation found by Fish are explained principally by the alternations of periods with a maximum of adult animals with those in which the zooplankton consists mainly of juvenile animals not caught by the nets employed. It may well be that the rate of grazing is unaffected to a large extent by these fluctuations in the zooplankton.

Patches of certain zooplanktonic species seem to occur fairly often both in coastal water and in oceanic water on the continental shelf. Patches of the copepod *Calanus finmarchicus* are regularly met with in the North Sea (Cushing, 1955). Such a distribution is easily explained by the complexity of the hydrographical conditions. It is somewhat doubtful, on the other hand, whether real patches of all kinds of zooplankton (not due to diurnal vertical migration) occur in the wide uniform oceanic regions far from the influence of the continental shelf or of divergences. According to the extensive "Dana" investigations published by Jespersen (1937) no patchiness appeared as a rule in the volume of zooplankton of all kinds (herbivores and carnivores) taken by stramin nets. The zooplankton at depths down to 300 metres was always fished by night only. This is undoubtedly an important point to be remembered.

4. The possibility of an inverse phytoplankton-zooplankton relationship

Phytoplankton is the food of the herbivorous zooplankton. In the long run therefore a large population of these animals is only possible where the production of phytoplankton is high. No-one seems ever to have doubted this. When we speak about an inverse relation between phytoplankton and zooplankton, we refer only to the momentary state of affairs, not the general relationship lasting over the whole year.

It is *a priori* possible for the sea to assume either more or less stationary conditions in which for instance the zooplankton population matches the production of phytoplankton or variable conditions in which periods of flourishing phytoplankton alternate with periods in which the standing crop of phytoplankton is eaten right down by the herbivorous zooplankton.

In the last 25 years the latter conception has been very prevalent. The sea is regarded as a place "where the animals enjoy alternating periods of overeating and starvation" and where "an equilibrium between standing crop of plants, herbivores and carnivores is continually passing in and out of balance" (Harvey, 1955, pp. 114 and 118).

On the other hand, Hentschel's investigations in the South Atlantic (see Fig. 1) showed striking similarities between the distributions of phytoplankton and zooplankton populations, although his material was collected in innumerable ocean sections made at all seasons of the year. In the tropics and

Figure 1 a.

Figure 1 b.

(a) Distribution of plankton organisms (numbers in thousands per litre) in the upper 50 m. layer.
(b) Distribution of zooplankton (metazoa) (numbers per 4 litres) in the upper 50 m. layer. After HENTSCHEL, 1933.

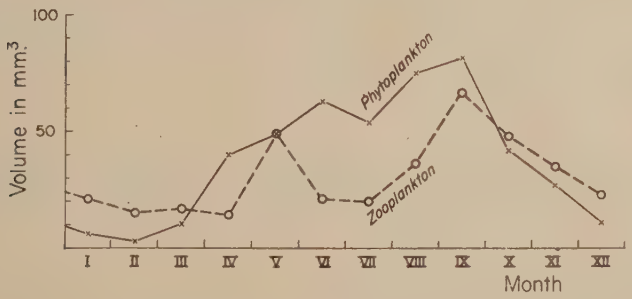

Figure 2. Monthly averages of the volumes of zooplankton and phytoplankton near Kiel. After LOHMANN, 1908.

subtropics the standing crop of both phytoplankton and herbivores must be fairly constant throughout the year.

A direct inter-relationship is also found in coastal waters. Figure 2 (after LOHMANN, 1908) shows the volumes (Rechenvolumen) of phytoplankton and zooplankton present in the Kieler Fjord in the course of a year. It is obvious that there is a direct relation between the quantities of phytoplankton and zooplankton. In the summer months the quantity of phytoplankton exceeds that of zooplankton. On the other hand in the darkest months of the year, when phytoplankton production is greatly reduced, the volume of zooplankton exceeds that of phytoplankton.

No assessments of zooplankton were made by the "Galathea" but the data collected by the expedition clearly show that the standing crop of phytoplankton in tropical and subtropical parts of the ocean remained fairly constant. This requires that the rate of grazing by the zooplankton was fairly even. It may be added that investigations made by the Danish Fishery Investigations with the carbon-14 technique in the northern part of the Atlantic in the course

of 4 summers (1954–1957) showed that for a given region the rate of organic production at that season is practically the same each year.

On the other hand, it is of course incorrect to assert that an inverse relation between phytoplankton and zooplankton can never obtain in the sea. Nevertheless such a state of affairs must be considered rather unusual. An example of "normal" inverse interrelation may be found in regions in which the conditions for phytoplankton production change suddenly from bad to good. This may occur in relatively high latitudes when in winter the water is unstratified down to considerable depths. In the spring, phytoplankton production once started proceeds vigorously, but it only starts when the water masses have been stabilized by the heating of the surface layer. This was first pointed out by BRAARUD and KLEM (1931). According to MARSHALL and ORR (1952), egg production in zooplankton species which hibernate is stimulated by the growth of phytoplankton. Consequently the production of zooplankton is delayed compared with that of phytoplankton. A short period with much phytoplankton and little zooplankton may thus occur. As the rate of grazing is low for a time due to the small stock of grazers a large crop of phytoplankton is quickly produced.

The use of net-caught samples for estimating the standing crop of phytoplankton has undoubtedly been the main background for the oft-repeated claims for the existence of an inverse relationship between phytoplankton and zooplankton in the sea. The different theories which try to explain it need not therefore be discussed here.

5. How is the balance between phytoplankton and zooplankton established?

It is of very great interest to try to understand the way in which Nature is able to maintain in a given oceanic region a fairly stable standing crop of plankton algae which regularly produces about the same amount of organic matter daily.

Plankton algae grown under laboratory conditions behave quite differently from those normally seen in nature. In the laboratory, scarcity of nutrients — for example those containing nitrogen and phosphorus — soon effects an absolute deficiency of these substances. The algae reach a state in which they do not grow at all. The respiratory rate is more or less unaffected, but the rate of photosynthesis is much reduced. After a fresh supply of the lacking nutrient has been added to a culture in which growth has stopped entirely, it takes a considerable time — in *Chlorella* more than 24 hours — before growth begins again (AL KHOLY, 1956). The rate of photosynthesis is unaffected for several hours at least (cf. STEEMANN NIELSEN and AL KHOLY, 1956).

If the growth of algae were not controlled by the grazing of animals or by other means, we should expect at least in the oligotrophic, tropical parts of the ocean periods with relatively much phytoplankton alternating with long periods in which practically no algae were present. However, HENTSCHEL's investigations on the "Meteor" expedition showed indisputably that on the contrary the standing crop of algae remains exceedingly steady in regard to both place and time.

In a particular oceanic region and at a particular depth, the curves showing the dependence of photosynthetic rate in the plankton on light intensity are, in principle, all similar. To the 12 series of experiments made with oceanic

surface water on the "Galathea" expedition (STEEMANN NIELSEN and AABYE JENSEN, 1957) may be added about 100 series more made with water from all depths of the photic layer obtained during cruises of the "Dana" in the North Atlantic and the Arctic during the summers of 1956 and 1957. In every experiment without exception, the rate of respiration is low in relation to the optimal rate of respiration. This is true both for eutrophic and oligotrophic water. A situation such as that suggested by RYTHER (1954) in which the rate of respiration in oligotrophic regions is about the same as the rate of optimal photosynthesis has never been met with. As shown by STEEMANN NIELSEN and AL KHOLY (1956) the occurrence in nature of such a situation is not very likely.

Accordingly, an equilibrium must normally exist between the growth of algae and their disappearance through grazing and sinking.

It is not at present possible to say with any certainty how this equilibrium is established. If the algae did not disappear at a fairly steady rate, the population of plankton algae would hardly remain constant. STEEMANN NIELSEN and AABYE JENSEN (1957) reckoned that in the oligotrophic, tropical parts of the ocean the daily net production of organic matter in the whole photosynthetic layer is about 25% of the organic matter contained in the algae. It was shown at the same time that almost all the loss of algae is caused by grazing either in the photic zone or — after they have sunk — immediately below this zone. The rate of grazing must thus be reasonably constant in these parts of the ocean.

As static conditions seem to prevail in most parts of the ocean, the size of the zooplankton population must be assumed to depend directly on the extent of the algal production. The detailed mechanism of this undoubtedly rather complicated and intricate relation between zooplankton and phytoplankton production is at present beyond our comprehension. In fact we may just as well say that the size of the phytoplankton crop depends directly on the rate of grazing.

In some way — as yet unknown — the growth of algae in oligotrophic regions must depend on the combined effects of grazing by the zooplankton, of being limited by the lack of some nutrient, and other circumstances. It seems fairly unlikely that the rate of replenishment of nutrients directly determines the rate of primary production, although the idea put forward *inter alia* by KETCHUM (1947) must nevertheless be considered valid: "It is the rate of replenishment, and not the concentration observed at a given time, which determines the fertility of an aquatic environment". The effect of replenishment is of an indirect nature.

The surface water of the Sargasso Sea can be characterized as extremely unproductive. About the lowest productivity observed anywhere in the oceans by the "Galathea" was found here (STEEMANN NIELSEN, 1954). Athough the water is extremely unfertile, it is nevertheless usually possible to detect small amounts of inorganic phosphate and nitrate even at the surface. For the western part of the Sargasso Sea, RILEY (1949, Fig. 6) has published a considerable body of data averaged by two-degree squares of latitude and longitude. East of 65°W. and south of 30°N., the concentration of phosphate-P is about 0·05 μg.-atom per litre, i. e., about the same as in many coastal areas during the height of production. On the "Galathea" cruise similar concentrations of inorganic phosphate were found in the surface water at all Sargasso Sea stations. Measureable concentrations of nitrate are also present in the region, as shown by both THOMSEN (1937) and RILEY (1949).

According to the measurements of primary organic production in the Sargasso Sea, the rate of photosynthesis must be about 1 mg. C per $m.^3$ per day near the surface (cf. STEEMANN NIELSEN and AABYE JENSEN, 1957, Table 20). If we may assume with REDFIELD (1934) that roughly 1 mg. P is assimilated for every 50 mg. C, the rate of phosphate assimilation may be estimated at about 0·02 mg. P per $m.^3$ per day. This is about 1 per cent. of the concentration of inorganic phosphate normally present here (0·05 μg.-atom P/l. = 1·5 mg. P/$m.^3$).

If it is assumed that conditions in the surface water of the Sargasso Sea are stable, the replenishment of inorganic phosphate may also be reckoned at about 0·02 mg. P per $m.^3$ per day. As fairly phosphate-rich water does not occur in the Sargasso Sea at depths less than several hundred metres and as the water masses in the eddy show a tendency to descend, the replenishment of inorganic phosphate in the surface water must be due primarily to regeneration within the surface layer itself. The daily phosphorus turnover seems to be extremely slow in relation to the concentration of dissolved inorganic P present at a given time. The turnover of phosphorus in relation to the P-content of the algae is, on the other hand, not slow; it must be of about the same amount as that of carbon in relation to the carbon content of the algae, that is, about 25% per day (STEEMANN NIELSEN and AABYE JENSEN, 1957).

The plankton algae very likely grow more slowly in the unproductive regions of the ocean than in the productive. The difference between the growth-rates is probably not too large, however. Calculations made (STEEMANN NIELSEN and AABYE JENSEN, 1957) indicates that the growth-rates in productive regions are about double the rates in unproductive. RODHE (1948) has arrived at a somewhat similar view for fresh water. He writes (p. 101):— "it is not said that the relative growth, consequently the increase per cell, is always greater in highly productive waters than in those poor in specimens. The results of the previous experiments give ground for the supposition that this should not always be the case".

Plankton algae must thus be able to assimilate phosphorus at a sufficiently high rate from very dilute concentrations of inorganic phosphate, provided these concentrations remain constant, either through a high regeneration rate, as in some eutrophic areas (cf. STEEMANN NIELSEN, 1951) or as the result of a very small standing crop of algae, as in the Sargasso Sea. In some places organic phosphate is perhaps also assimilated, but this can hardly be the case in an oligotrophic oceanic area.

A concentration of phosphate of 1·5 μg. P/l. — such as found in the Sargasso Sea — must be considered adequate for the normal growth of many species of plankton algae. According to RODHE (1948) the growth-rate of the fresh-water diatom *Asterionella formosa* in lake water is constant down to a concentration of 2 μg. P-P_2O_5/l. The flagellates *Dinobryon divergens* and *Uroglena americana* were shown to have still lower phosphorus requirements.

It could of course be argued that the algal production in the Sargasso Sea is limited by some nutrient other than phosphate or nitrate, the availability of the latter being at least as good as that of phosphate. Such an idea cannot be absolutely ruled out; although it seems rather improbable. As already pointed out on p. 184, in laboratory experiments absolute deficiency of a substance has the effect of transforming the algae — at least species like *Chlorella pyrenoidosa* — into a state in which they do not grow at all. It was shown that such conditions do not occur in the relatively unproductive parts of the oceans.

Hence it must be assumed that algal growth is directly controlled by factors other than the deficiency of necessary substances. One of these factors is very likely the rate of grazing by zooplankton. Another is possibly the production of auto-inhibitors by the algae themselves (PRATT, 1942; JØRGENSEN, 1956). The puzzling problem thus is: How is it that Nature arranges matters so that as a rule the grazing of the zooplankton maintains the standing crop of phytoplankton at the size best suited to prevailing growth conditions?

The present extent of our knowledge does not seem sufficient to allow any definite answer to be given. We suspect, however, that external metabolites given off by both algae and zooplankton may have at least some connexion with the establishment of the balance between producers and consumers in the ocean. As LUCAS (1955) so convincingly presented the case, we are now obliged to believe that ecological inter-relationships exist in the sea which are as important as the already familar relationships existing between the organism and its physical environment, and between prey and predator. It may be predicted that an essential part of oceanographic study in the coming years will be work along such lines.

Another possible prime factor in the establishment of a balance between producers and consumers in the ocean is natural selection among the species occurring in the different areas. This concerns, of course, both plants and animals. The most abundant species are almost invariably of a kind best adapted to the particular conditions. In the long run the best results are undoubtedly obtained under steady-state conditions. The organisms which are able to achieve this state will thus oust all competitors.

Summary

A direct relationship between phytoplankton and zooplankton is normal in the sea. The claims for an inverse relationship and the various theories which try to support this conception seem mainly to result from the use of net-caught samples for estimating the standing crop of phytoplankton. The use of nets of coarse silk may at the same time lead to the amount of herbivorous zooplankton being underestimated, expecially in periods when small organisms — for example, nauplii — predominate.

It is shown that as a rule grazing by the zooplankton maintains the standing crop of phytoplankton at the size best suited to prevailing conditions. The result is that with stable hydrographic conditions such as occur mainly in tropical and subtropical regions, the standing crop of phytoplankton and its production is stable. The circumstances which may lead to establishment of conditions of balance are discussed.

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Mechanical Pipette for Picking Out Diatoms

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From the work of Gross (1937) it was evident that an essential part of the preparation of marine diatom cultures was the use of a capillary pipette for picking out individual cells in sterile media. This is not only a laborious process in itself, but as Pringsheim (1946) points out, the larger diatoms are not easily collected by capillarity because a wide-mouthed pipette must be used, which results in loss of capillary force. The washing technique would be thus considerably enhanced if it were mechanized and a force other than capillarity employed. This paper describes an electrically controlled pipette by means of which individual diatoms can be washed quickly and in fairly large numbers.

Description

The instrument is illustrated in Figure 1, with a circuit diagram. A Trevan's microsyringe, consisting of a glass pipette and a micrometer, both attached by clamps (C) to a steel rod, has been adapted. A small spring (S) placed on the syringe plunger provides the mechanical power for suction and is cushioned against the plunger head by a very small rubber band (R). Since the syringe clamp does not tighten directly on to the syringe, but through rubber packing, a brass washer (W) behind the flange of the syringe barrel prevents the micrometer spindle from pushing the syringe through the clamp. A detachable right-angled glass pipette (P), with an inside diameter of 0·4–0·5 mm. at the mouth, is used with the syringe. A gear wheel (G1) of $2^{5}/_{8}''$ diameter is fixed to the micrometer spindle by means of a grubscrew. The steel rod holding the microsyringe is clamped to a retort stand.

A small electric motor, 24 volts DC, 0·5 amp., is used for turning the micrometer spindle. Incorporated in it is a solenoid-operated brake which stops the motor immediately the current is switched off. The motor is operated by a foot-switch (FS) and the circuit includes a reversing switch (RS). As a safety device, the lever (L) of a microswitch (MS) is positioned so that it switches off the current when the plunger spring is almost fully depressed (i. e., the pipette is empty), thereby preventing the micrometer spindle from bearing too hard against the glass plunger. Fixed to the spindle of the motor is a gear wheel

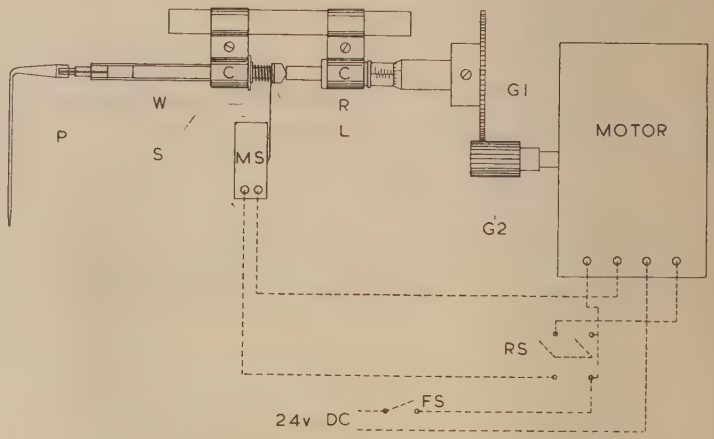

Figure 1. Layout of apparatus with wiring diagram (for explanation of lettering, see text).

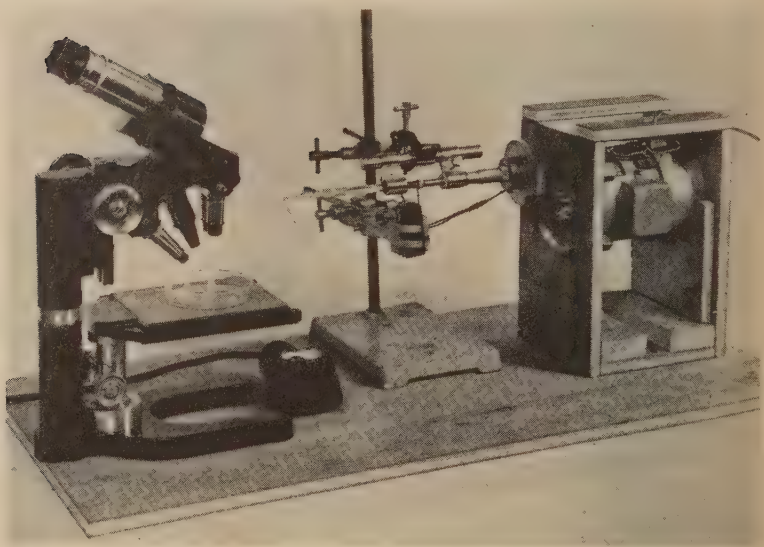

Figure 2. Apparatus in the ejection position.

(G2), 1″ long by $^{11}/_{16}$″ diameter, into which fits the micrometer gear wheel. The motor is bolted to a wooden framework. The retort stand and motor framework are screwed securely to a baseboard.

A Watson "Greenough" dissecting microscope is used with a frosted-glass stage adapted to rack up and down. The × 12 eyepieces and 45 mm. objectives are found to be the most useful for picking out diatoms. The microscope is bolted to the baseboard through its left foot.

Operation

The mouth of the pipette should appear at the top of the microscope field and slightly above the bottom of the Petri dish. While the left hand is used to move the dish, the right hand can be used for cleaning diatoms, clearing detritus, or releasing diatoms adhering to the bottom; this has been done quite easily with a needle without harm. Glass dishes are not perfectly flat but by raising or lowering the stage the pipette can be kept in position just above the bottom. To pick up, the diatom is moved near the mouth of the pipette and the foot-switch operated. The motor, through the gear wheels, turns the micrometer thimble and withdraws the spindle, allowing the syringe plunger, under the impetus of its spring, to withdraw also, sucking the diatom into the pipette. Only a very quick pressure and release on the foot-switch is necessary, involving a movement of about 0·015″ of the micrometer. The brake on the motor prevents the pipette from sucking after the foot-switch is released. As many as 100 cells or more can be drawn into the pipette before emptying is necessary. The contents of the pipette must not pass into the syringe. Because of its spring, the plunger cannot reach the bottom of the syringe and any liquid in the space at the bottom of the syringe cannot be expelled. To discharge the pipette, the microscope stage is lowered, so that the mouth of the pipette clears the rim of the Petri dish. The microscope, pivotted on its bolt, is then swung to one side. The reversing switch is operated and the foot-switch depressed thus ejecting the contents of the pipette. The glass pipettes are easily removed and the writer keeps a stock of them in boiling distilled water, using one for each wash. They are not, unfortunately, of uniform size, but by moving the microscope to left or right and by raising or lowering the stage, the mouth of the pipette can be positioned correctly.

This apparatus has been in use at the Lowestoft Laboratory for over a year and has been found a satisfactory tool in the preparation of uni-algal cultures of the larger diatoms.

Summary

In the washing technique of diatom culture, picking up the diatoms is a very laborious process. This is particularly so in the case of large diatoms, in which the necessary use of a wide-mouthed pipette results in the reduction of capillary force. An electrically controlled apparatus is described which picks up the larger diatoms mechanically. It requires no special parts and is made from easily available components.

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Mesh Selection in Plankton Nets

By

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Introduction

The material used in the construction of plankton nets, unless and until clogging occurs, acts like a filter; it retains certain organisms, and allows others to escape, according to the relative size of organism and mesh of the silk. This fact is fully appreciated by most plankton workers, who treat their results with caution, when they suspect that the organisms with which they are dealing are near the size at which escape is possible. A more accurate measure of the selection characteristics of silks used in plankton nets would, however, seem highly desirable to allow greater precision in the consideration of this factor.

The problem was first discussed in some detail by GIBBONS (1939). He listed some of the commoner plankton organisms as being retained, partly retained, or completely lost, by fine-silk, Hensen, and cheesecloth nets. Unfortunately he gave no indication as to how these conclusions were reached. WIBORG (1948) gave a more satisfactory treatment of the problem. He measured the aperture of the meshes of some of the standard grades of Dufour bolting silk, as well as the body dimensions of several copepods in their various stages; from a comparison of the two sets of measurements, he deduced which organisms would be retained by the various grades of silk. Although giving useful approximations, this approach seems to be lacking in two major respects. Firstly, it assumes a direct relationship between mesh-size and size of retention, which may not apply in practice. Secondly, WIBORG's technique gives results in terms of complete retention, or complete escape. Actually it seems more likely that there is a gradation from complete escape to complete retention, with increasing size of organism.

It appeared that a more satisfactory measure of the selection characteristics of plankton nets would require an empirical approach, and an adaptation of the methods used in analysing selectivity in commercial fishing gear seemed most suitable. This paper deals with the treatment of some samples taken by the research ships of the Scottish Home Department with this problem in mind and subsequent laboratory experiments designed to clarify the mechanism underlying the results obtained.

Methods

The initial experiments were designed to measure the escape characteristics of silk with 60 threads to the inch (International No. 3). This grade of silk is probably the one most widely used in plankton work — e. g., in Hensen nets, in Hardy Plankton Indicators and Plankton Recorders, and in several other plankton nets. The silk used in this laboratory is John Staniar & Company's Quadruple Extra Heavy Quality Grit Gauze, corresponding in mesh-size to No. 3 on the Dufour scale. This silk has a square mesh aperture when new of 0·312 mm. It is recognized, however, that the silk shrinks when wet, giving a smaller mesh-size, and a further reduction in mesh-size occurs with use. Accordingly samples of new and used silk were measured dry, and after immersion in water. The mean mesh-sizes of these samples, and their standard errors, are given in Table 1.

Table 1

Silk	Mean mesh-size (mm.)	S. E.
New silk (dry)	0·312	±0·0034
– – (wet)	0·261	±0·0029
Used silk (dry)	0·236	±0·0040
– – (wet)	0·221	±0·0073

As the nets used in these experiments had seen a good deal of service, the figures in the last row of the table seem most applicable to the results which follow.

The net used was 39″ in diameter at the mouth and 6 feet in length; it tapered to a canvas collar, 4″ in diameter, to which was attached a bag of the same silk to contain the catch. This net was fastened to a 1-metre diameter ring and outside it, but attached to the same ring, was rigged another net of bolting silk with 180 threads to the inch. This had the following dimensions:— mouth opening of 39″ diameter, overall length of 7′5″, tapering to a canvas collar, 7″ in diameter. This collar also had a detachable bag to contain the catch, made of the same silk as the net. Thus, all the water passing through the 60-mesh net was again filtered by the 180-mesh net, and no water, or only a negligible volume, passed directly through the outer cover.

Samples were taken with this gear by means of vertical hauls from bottom to surface, the apparatus being hauled directly by winch, at an average speed of half a metre per second. On reaching the surface both the inner net and the outer cover were carefully washed down before the detachable bags, containing the catches from the two nets, were removed. The two samples from each haul were preserved separately in 4% formaldehyde. Six hauls were made with the gear from the F.R.S. "Explorer" at various positions in the northern North Sea between 12. March and 2. April 1955, and a further ten hauls at stations in the same area between 26. June and 9. July 1955.

In the laboratory the numbers of each category of the organism considered were estimated by taking subsamples from a known volume with a Stempel pipette in the standard way. Measurements of the body dimensions of organisms were made with an eyepiece micrometer in a binocular microscope. Copepods were identified only to genus — *Calanus* being subdivided into adults and copepodids; nauplii were roughly subdivided whilst the samples were counted

into large and small nauplii. Other organisms were merely identified in broad groupings such as lamellibranch larvae, polychaete larvae, etc.

Subsequent experiments were made with another grade of silk. In these the silk investigated was John Staniar & Company's Quadruple Extra Heavy Quality Grit Gauze with 16 threads to the inch. This grade of silk when wet and used has a mean mesh aperture of 1·188 ± 0·010 mm.

The net in these later experiments was 8″ in diameter at the mouth, 1 foot long, tapering to a collar 2½″ in diameter. This net was attached to an 8″ diameter ring and was provided, as in the previous experiments, with a slightly larger cover of silk with 26 threads to the inch. Samples were taken with this gear by means of subsurface tows of 10 minutes duration at an approximate towing speed of 2 knots. The samples were preserved in the same way as in the previous experiments. Thirteen tows were made with this gear from the F.R.S. "Explorer" in the northern North Sea in May 1956. From these hauls fish eggs only were considered, all eggs being removed from the two samples provided by each tow, and measured and counted.

The laboratory experiments can be divided into two groups, "bag" experiments and "diaphragm" experiments. In the "bag" experiments conical bags of various grades of silk 2″ in diameter and 4″ long were made up. These were attached to outer covers of a finer grade than was being investigated. The bags were immersed in a container of water with the ring just breaking the surface. A flow of water was introduced into the bags by rubber tubes led from the laboratory taps, giving a volume of 35 litres per minute. Glass beads of two grades (English Glass Co.'s Crystal Ballotini No. 3 and No. 10) were gradually introduced into the stream of water flowing through the nets during the course of the experiments, each of which lasted ten minutes. Afterwards the spheres were removed from the inner bags and outer covers, counted, and measured. The diaphragm experiments were conducted in a similar way, but in place of the inner bag, a piece of silk was clamped tightly stretched across the end of a piece of polythene tubing, 3″ in diameter.

Results of 60-Mesh Experiments

In the case of 60-mesh experiments, the results from the two groups of hauls were first considered separately. However, although the percentage release for some organisms varied considerably between the groups, these differences were not significant, and accordingly the cruise data were combined to give the mean percentage releases, which, together with their standard errors, are given in Table 2. As all the organisms listed did not occur in every haul, the number of observations on which the means are based are given in brackets in the standard error column.

From Table 2 it can be seen that, in the population sampled, the only organism which is almost completely retained by the grade of silk is adult *Calanus*; the release of *Metridia* and *Temora* is perhaps for many purposes insignificant. It may also be noted that there is a definite relationship between the size of the mean and the size of its standard error, small and large means having in general small standard errors and intermediate values being associated with large standard errors.

One might have expected that clogging effects would play some part in

Table 2

Organism	Mean % release	S. E.
Calanus (adults)	0·7	± 0·5 (16)
– (copepodids)	20·4	± 4·5 (16)
Metridia	6·6	± 1·0 (10)
Temora	13·0	± 5·4 (9)
Acartia	37·9	± 5·6 (5)
Pseudocalanus	52·5	± 8·1 (6)
Microcalanus	77·6	± 2·1 (10)
Oithona	92·0	± 2·0 (16)
Harpacticids	99·5	± 0·6 (16)
Nauplii (large)	86·8	± 3·6 (12)
– (small)	98·5	± 0·5 (16)
Evadne	31·7	± 4·7 (2)
Gastropod larvae	89·1	± 3·7 (16)
Lamellibranch larvae	72·0	± 9·2 (13)
Polychaete larvae	87·0	±11·5 (9)
Oikopleura	39·5	±10·7 (16)

causing the variability found between hauls. If this were so, there ought to be a relationship between the size of the sample (as measured by its settled volume) and the percentage escape of any selected organism. An examination of the data disclosed no such trend. Moreover, if clogging had played a significant part in affecting release in any of these samples, one would expect the deviations from the mean release for all organisms in that sample to be negative. This in fact did not occur, positive deviations for some organisms and negative ones for others being a feature of all the samples. Clogging effects being eliminated, as having played no important part in affecting release, the results obtained should be explicable on a straight-forward relationship between organism size and mesh-size of the silk.

A random sample of 50 individuals from each group of organisms was measured from each sample. From these measurements the size frequencies of the total population and of the proportion of it which was released were estimated and the percentage release calculated for each size category. On this basis highly consistent results were obtained between hauls and between cruises for all organisms. In Figure 1 the percentage release values for all the hauls are plotted against size for the various organisms considered, and curves giving the best fit to the data are drawn.

From the graphs of Figure 1, the maximum size of complete escape, the 50% release point, and the minimum size of complete retention for selected organisms have been extracted to provide Table 3.

Table 3

Organism	Complete escape mm.	50% release point mm.	Complete retention mm.
Calanus	0·212	0·268	0·326
Pseudocalanus	0·227	0·317	0·378
Microcalanus	0·250	0·288	0·326
Temora	0·250	0·288	0·326
Oithona	0·099	0·208	0·231
Nauplii	0·227	0·288	0·326
Gastropods	0·237	0·279	0·317
Lamellibranchs	0·237	0·284	0·336

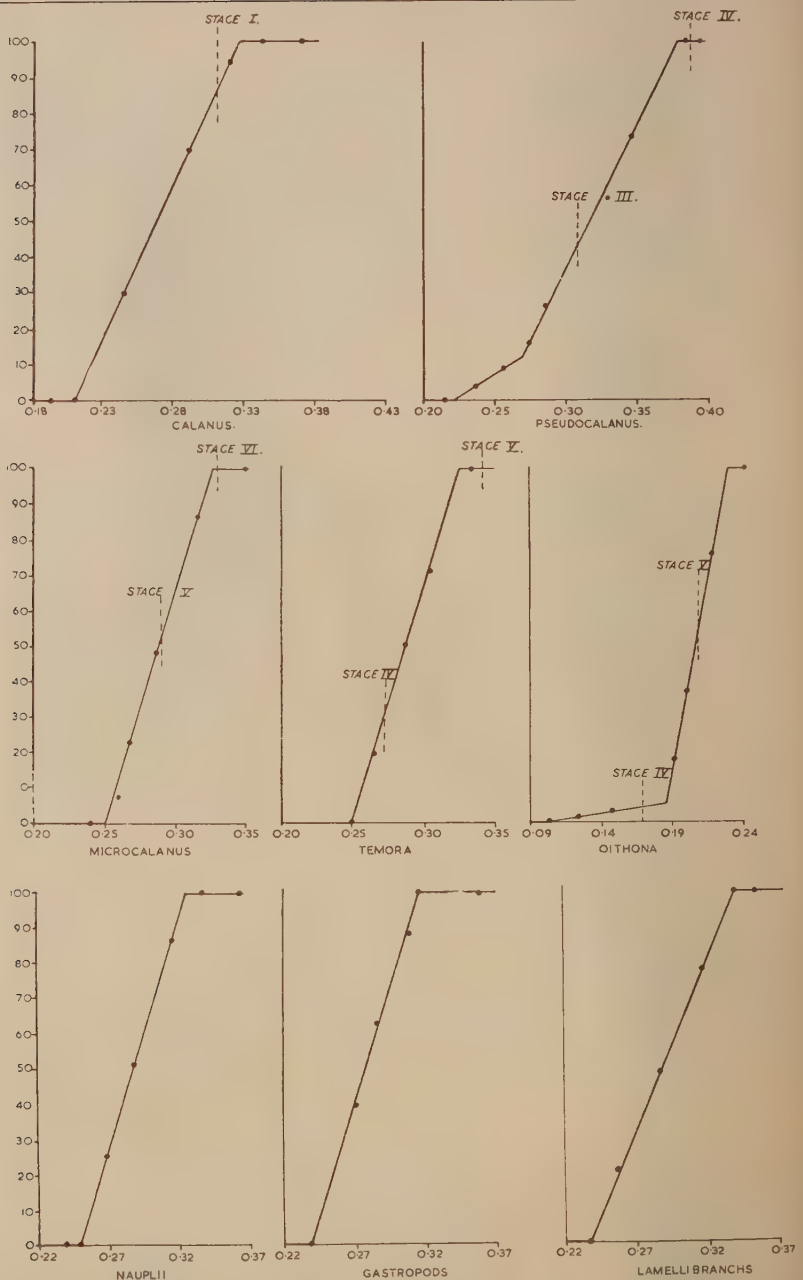

Figure 1. Selection curves of 60-mesh silk for some typical plankton organisms. The Y-axes represent the percentage of the population retained; the X-axes the greatest breadth of the organisms in millimetres. The broken vertical lines indicate the mean sizes of the corresponding copepodid stages.

The agreement within the body of data is as close as could be expected, with the exception of *Oithona*. This species appears to be retained at a smaller size than the other organisms considered. In relation to this it is perhaps significant that about 90% of the specimens of this genus examined had the antennae extending outwards from the body, in contrast to the majority of the other species of copepods, in which they were closely pressed along the body. Extended they would considerably hamper the escape of the animal through the meshes and this would seem the most likely explanation of the retention of this species at an apparently lesser girth than any of the other organisms considered.

The mean width of the other seven groups which gave reasonably consistent results are 0·234 mm., 0·287 mm., and 0·334 mm. for complete release, 50% release, and complete retention, respectively. It is of interest to compare these values with the mean mesh-size of the silk in question — 0·22 mm. (Table 1); even the minimum size for complete escape is considerably greater than this mean mesh-size. However, the measurement of mesh-size given is the length of side of a square mesh. One would expect this dimension to coincide with the greatest width of the organisms retained only if the meshes of the net were assumed to be rigid and square in shape. The data from Table 3 would seem to cast doubt on the validity of this assumption.

Another group of experiments strengthened this conclusion. The data were derived from a large number of paired hauls with one-metre tow-nets of similar dimensions but made of bolting silk with 26 threads and 60 threads to the inch. A comparison of the catches from these hauls revealed that although they caught effectively identical numbers of herring larvae above a length of 13·5 mm., below this size the 60-mesh net caught consistently more than did the 26-mesh. The most plausible explanation of this appeared to be that larvae of less than 13·5 mm. were excaping through the meshes of the 26-mesh net. The greatest breadth, the greatest depth, and the total length of a number of larvae were measured. The mean diameter of 13 mm. larvae was found to be 0·83 mm., and that of 14 mm. larvae 0·89 mm. The length of a side of a mesh of 26 silk was 0·67 mm. (S.E. $\pm$0·014). These data then would again suggest release at a considerably greater size than would be predicted from the measurements of a square rigid mesh.

The inferences from these data seemed of sufficient importance to require further investigation. As a first step, it appeared necessary to collect more satisfactory data to show how far the conclusions derived from the 60-mesh silk experiments were applicable to other grades of bolting silk. Because the simplicity of their external form makes possible a high degree of accuracy in measurement, and a less ambiguous appraisal of the results, it was decided to investigate this on a population of fish eggs. In these experiments the inner net was made of silk with 16 threads to the inch; the outer cover had 26 threads to the inch. A total of thirteen samples were taken with this gear, of which only six contained sufficient numbers of eggs of the critical size to provide independent release curves. The mean 50% release point, estimated from these six sets of data, was 1·387 $\pm$ ·031 mm. The combined data for eggs from all thirteen hauls gave an estimate for the 50% point of 1·403 mm. (Fig. 2). The mean mesh-size of the silk used in this experiment, measured wet, was 1·188 $\pm$ ·010 mm. It is clear from these results that for 16-mesh silk the 50% release point is also significantly higher than one would expect on the basis of a rigid mesh.

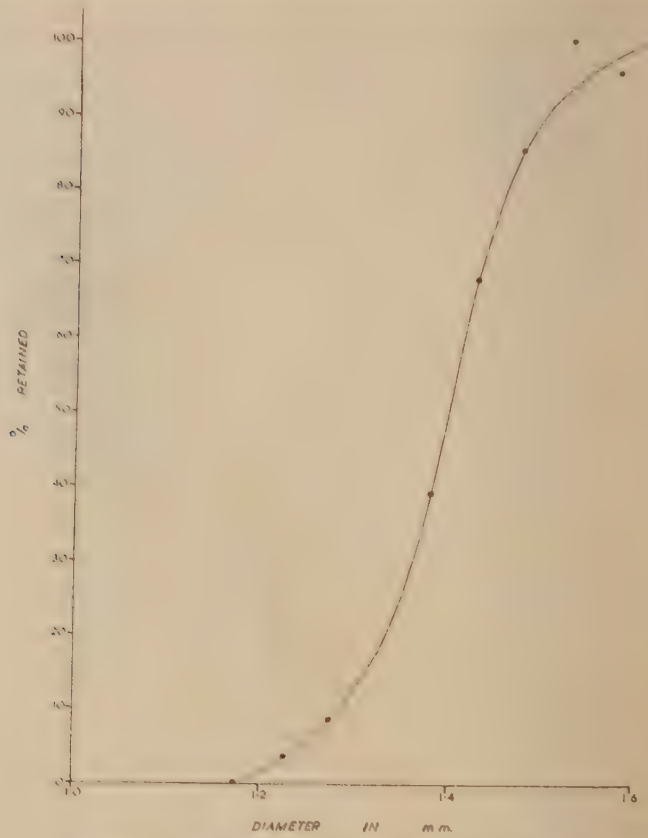

Figure 2. Selection curve of 16-mesh silk for fish eggs.

The question which then arose was whether the flexibility which must be postulated to explain these results resided in the meshes of the silk or in the organisms which were passing through them. To resolve this point, laboratory experiments were carried out with incompressible glass balls instead of living organisms. The technique used in these experiments has already been described (p. 194).

Eight of these experiments were made with an inner bag of silk of 16 threads to the inch, two with an inner bag of 26 threads to the inch, and two with an inner bag of 60 threads to the inch. The 50 % release points obtained from these experiments are given in Table 4.

The parameters from these experiments have been brought together in Table 5.

It may be seen that the 50 % release points from two of these experiments are intermediate between those found under normal fishing conditions for living organisms and those expected from the mesh-size of the silk on the assumption of a rigid square mesh. They strongly suggest that the high release values found

Table 4

Grade of silk	50% release point, mm.	Mean mesh-size, mm.
16 threads per inch	1·24 1·25 1·34 1·38 1·22 1·25 1·26 1·26	1·189 ± 0·011
26 threads per inch	0·73 0·74	0·676 ± 0·008
60 threads per inch	0·255 0·266	0·222 ± 0·003

Mean 50% point for 16-thread silk 1·275 ± 0·0207
– 50% – – 26 – – 0·735 ± 0·0050
– 50% – – 60 – – 0·261 ± 0·0055

Table 5

Grade of silk	Mean mesh-size, mm.	50% release point: living organisms, mm.	50% release point: glass balls, mm.
60 threads per in.	0·222 ± 0·003	0·287	0·261
26 – – –	0·676 ± 0·008	?	0·735
16 – – –	1·189 ± 0·010	1·403	1·275

under normal conditions are due to the additive effects of two factors, (a) a "compressibility" which permits the organism to squeeze through a smaller mesh than would be expected from a consideration of the size of its natural cross-section, and (b) a mesh "flexibility" which allows even incompressible objects to be released at a larger size than would be predicted from the measured mesh-size.

It is useful to consider at this point how these tap experiments differed from normal towing procedure and hence how comparable the figures in the last two columns of Table 5 really are. The main difference would seem to be that, whilst normally the net is towed through an effectively static body of water, in these experiments the net was static and the water was forced through it. This should not affect their comparability provided the pressure of water within the net was the same in both cases. The taps delivered 35 litres of water per minute through the bags. In the size of bag used this is equivalent to a hauling speed of 0·5 metres per second for a vertical haul or a towing speed of 1 knot for a tow-net. This is equal to the speed at which the 60-mesh net was hauled but only half the nominal speed of towing the 16-mesh net. However, at such low speeds it is very difficult to control the towing speed accurately and the speed of towing may well have fallen as low as 1 knot on occasions.

If one accepts the figures derived from these two types of experiments as comparable, then, by subtracting the last column in Table 5 from the third one, one gets a measure of the compressibility of the organism. The two figures so obtained are 8·8% and 9·1% of the size of the corresponding organism, which suggests that the compressibility is a direct function of organism size. Subtracting column 2 from column 3 one gets a measure of the "flexibility" of the meshes themselves. It may be seen that although the mesh "flexibility"

increases with increasing mesh-size the relationship is not one of direct proportionality. The numbers of observations are too few to give a really satisfactory regression equation but an equation of the form $\hat{y} = 0{\cdot}049x + 0{\cdot}027$ gives a reasonably satisfactory fit to the data.

It is now necessary to consider the source of this flexibility in the meshes. When a net is being towed one would expect the forces acting on the net to keep the threads comprising the meshes too taut to allow them to conform to the shape of an organism passing through them, and photographs of trawl nets being towed confirm that this tends to occur there. However, it did seem possible that flow conditions peculiar to a conical bag type of net might result in the meshes retaining some measure of flexibility. To test this possibility the diaphragm experiments described on page 194 were carried out. These experiments duplicated those previously carried out with glass beads, apart from the fact that in place of a conical bag the filtering unit was a piece of 16-thread silk so tightly stretched as to obviate any possibility of the threads being flexible. Two of these experiments were done and gave 50% release points of 1·275 and 1·285 mm. The silk used again had a mean mesh-size of 1·189 mm. Now these values fall within the range found for the same grade of silk in the bag experiments (Table 4) and would suggest that the mesh flexibility found in these experiments was not due to any limpness in the meshes brought about by conditions peculiar to a conical type of bag. The source of mesh "flexibility" then must be sought in the construction of the silk itself. Two facets of this seem relevant to the problem. Firstly, the meshes are not knotted at the corners, as in a trawl. The weft is made up of two threads, one of which passes over and one under the warp. They are then twisted in the centre of the space between the two warp threads before passing over and under the next warp thread. This results in the corners of the meshes being formed by the warp threads lying in a loop of the weft threads, a loop whose dimensions are governed by the size of the mesh aperture and by the thickness of the threads. Secondly, the threads used in the construction of the silk increase in thickness with increasing mesh-size but by no means in proportion to the mesh-size. In 60-mesh silk the thread thickness is about equal to the mesh aperture when wet, in 26-mesh silk it is about half the mesh aperture, and in 16-mesh slightly less than a third. There would thus seem to be two possible sources of mesh "flexibility" — firstly, a certain measure of compressibility of the threads themselves, which would add proportionally more to the apparent flexibility in the smaller apertured silks. Secondly, the threads of the warp may be able to move somewhat within the loops formed by the threads of the weft, and thus allow an increase in the size of any individual mesh which would be roughly proportional to the mesh aperture. It is tempting to ascribe the proportionate factor in the regression equation to this latter source of flexibility and the constant to the compressibility of the threads. The equation is, however, founded on too few observations to make further development of this idea profitable.

Summary

To measure the extent of escape of various plankton organisms from a net made of silk with 60 threads to the inch, sixteen hauls were made with a net of this material, fitted with an outer cover of finer mesh.

The percentage escape of any species gave consistent results when plotted against size. From these graphs it can be deduced that *Calanus* is fully retained by this grade of silk only above the second copepodid stage, *Pseudocalanus* above Stage IV, and *Temora* above Stage V.

The data show release at a greater size than is compatible with a rigid square mesh and this conclusion has also been shown to apply to other grades of bolting silk.

Laboratory experiments to investigate this situation have shown that the high release is due partly to a capacity on the part of the organism to be compressed and partly to a distortion of the meshes explicable from the nature of their construction.

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A Basis for Comparing Grabs

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Introduction

In productivity studies of the benthos, in which grabs are used, it is usual to refer quantities to a unit surface area. This assumes that the grab samples at an even depth, so that the results represent all the animals dwelling below a unit area. However, a grab, with its horizontally placed spindle, cuts out an arc, so that a smaller quadrat is sampled from the greater depths. This makes it difficult to obtain a true comparison between any two instruments, or surveys, or even samples, because of differences in the depth of biting. Ursin (1954) showed that the number of animals beneath a unit area increased with sample volume, until a maximum density was reached. All comparisons between sampling instruments show the same effect (Thamdrup, 1938; Johansen, 1927; Holme, 1949; Smith and McIntyre, 1954; Ursin, 1954 and 1956). The fact that some species burrow deeper than others, and that older individuals of some species burrow deeper than young ones, also means that a generalized ratio of efficiency based on numbers cannot be applied in the comparisons. This fact also has a bearing on the apparent variability of species densities.

Method

In 1953 I made two comparative tests, using four grabs in all, from the research vessel "Sir Lancelot" on the Dogger Bank. The four grabs were as follows, all sampling 0·2 m^2.

(a) Petersen — the grab used by Davis (1923, 1925).

(b) van Veen-type grab (Thamdrup, 1938). This departs from the original design in being operated by chains of fixed length instead of warps.

(c) and (d) van Veen grabs, operated by endless warps running over pulleys. In series (c) the grab had side-plates to prevent loss of material during closing, as suggested by Orton (1925). No previous tests of this device are recorded. In (d) the side-plates were removed.

At each station the "Sir Lancelot" was anchored, so that substantially the

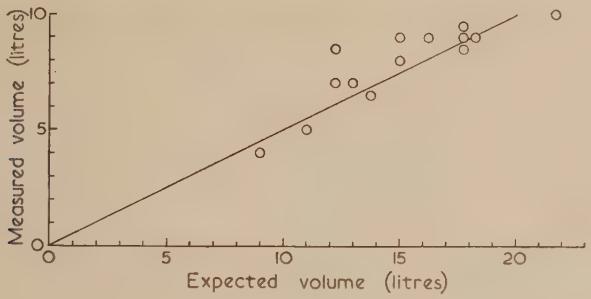

Figure 1. Measured volume of sample against expected volume (in litres).

same community was sampled throughout the series of hauls. The details of the stations and tests are as follows:—

Station 110, Cruise VIII, May 1953
Position: 54°57′N., 2°50½′E. Depth: 12 fms.
Bottom: Soft, slightly muddy sand with much shell.
Test: Petersen and chain van Veen, 5 hauls with each, repeated to 20 hauls.

Station 1, Cruise XV, October 1953
Position: 54°18′N., 2°07′E. Depth: 19 fms.
Bottom: Firm sand.
Test: All four grabs, 5 hauls with each, in the order b, a, c, d.

A dipstick was used in the van Veen grabs to ascertain the maximum depth of digging; this consisted of a brass rod, with pockets drilled downwards at 2 cm. intervals from the lower end. When the grab was hauled inboard, six readings of the depth were taken by pushing the dipstick right down to metal through a series of holes alongside the hinge, twisting, and extracting it; the numbers of pockets containing sand were then recorded. For a sampler 0·2 m.² in area, the expected volume of the sample would be 2 litres per 1 cm. of depth. The expected volumes at the second station have been plotted (Fig. 1) against actual volumes, as measured in a graduated bucket after sieving.

Results

The lowest measured volumes at each expected volume lie roughly on a straight line, the slope of which agrees with a ratio of 1:2 between measured and expected values. Thus the lowest efficiency of the grabs was 50%, which would mean that the grab dug along a section as at "a" in Figure 2. When the ratio is less than 1:2, the efficiency is greater than 50% and the section cut out by the grab is more like that at "c" in Figure 2.

The efficiency of each van Veen grab at the station of October 1953 is shown in Table 1. The use of warp instead of chains raises the volume by 50% though not the efficiency, but the addition of side-plates raises the efficiency over that

Figure 2. Profiles of grab samples.
e – expected. a – 50% efficiency. c – over 50% efficiency.

with no side-plates, though the volume is slightly less. The greatest increase in numbers of *Tellina*, however, comes from the use of warps and the increased volume of sample.

Table 1

Efficiency (measured volume as % of expected volume) of van Veen grabs "Sir Lancelot" Cruise XV – October, 1953

Grab	Efficiency (Average of 5 hauls) %	Average volume l.	Average number of *Tellina* per haul
Chains	51·4	6·2	22·0
Warp	52·2	9·0	34·6
Warp with guards	56·1	8·6	27·4

The numbers per haul of the more numerous species are shown in Figure 3, plotted against volume. In most cases the regression of numbers upon volume is practically linear, but the regression coefficients differ for each species. Thus the simplest basis for comparison of different instruments, and of hauls with the same instrument, is the number of animals per unit volume of soil. In Figure 3 (A) it may be seen, however, that after a volume of about 3·5 l., the curve tends towards an asymptote. This is because all the *Mactra* lie in a fairly shallow stratum (3–4 cm., from observations in the grab) and any increase in the depth of digging beyond this depth, would not catch any more *Mactra*. The volume beyond which an increasing proportion of soil lacking in the species is sampled I have called the "critical volume". With species like *Mactra*, for which the critical volume is thus known from a series of hauls, the calculation of volume density is straightforward, for samples not exceeding the critical volume; whenever the sample volume exceeds the critical, the number per sample is divided by the critical volume found. In either case, the true area density is then obtained by multiplying the volume density by the total volume (under a unit area) of the stratum occupied by the species. Of the species named in this paper, this can be done for one, *Mactra corallina*.

The densities, per litre, of some of the animals at these two stations were plotted against volume of sample; the results appear in Figure 4. There is a wide scatter of points, and two types of distributions occur. In some there is no regression of density upon volume (*Tellina*, Cruise XV, 1953; *Scolelepis*, Cruise VIII, 1953), which must mean that the critical depth is beyond the sampling depth. In some there is a negative regression (*Mactra*, Cruise VIII, 1953), which shows that the critical depth lies within the sampling depth.

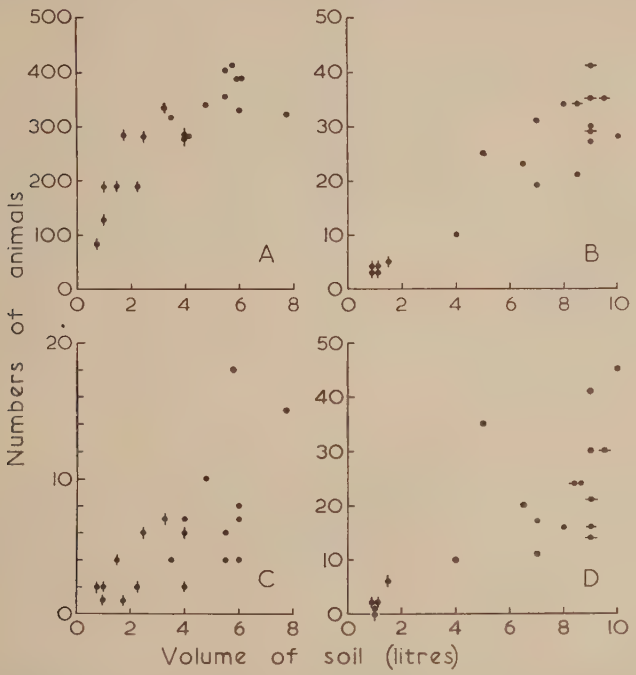

Figure 3. Numbers of each named species per haul (0·2 m.²) plotted against volume of soil (l.). Observations with the Petersen grab are indicated by a vertical bar (⌽), those with the van Veen with warps by a horizontal bar (⊖). Remaining observations were with the van Veen with chains, or with side-plates.

A – *Mactra corallina* (Cruise VIII, 1953). C – *Scolelepis ciliata* (Cruise VIII, 1953).
B – *Tellina fabula* (Cruise XV, 1953). D – *Magelona papillicornis* (Cruise XV, 1953).

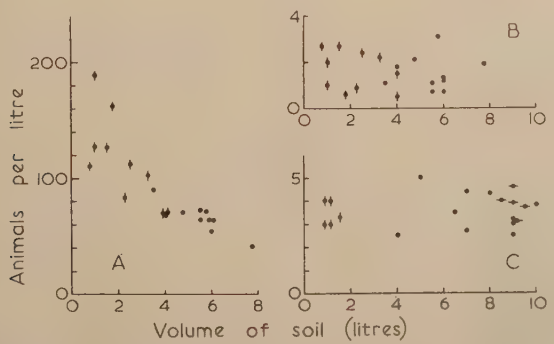

Figure 4. Number of each named species per litre of soil. Observations with the Petersen grab are indicated by a vertical bar (⌽), those with the van Veen with warps by a horizontal bar (⊖). Remaining observations were with the van Veen with chains, or with side-plates.

A – *Mactra corallina* (Cruise VIII, 1953).
B – *Scolelepis ciliata* (Cruise VIII, 1953).
C – *Tellina fabula* (Cruise XV, 1953).

Table 2

Comparison of density per unit area and density per unit volume

(a) Cruise VIII, 1953

	Number per 0·2 m².		Number per litre	
	Petersen	van Veen with chains	Petersen	van Veen with chains
Average volume (l.)	2·20	5·48	2·20	5·48
Species:—				
Mactra corallina	224·5	353·2	115·79	66·70
Ensis ensis	1·1	2·1	0·46	0·36
Tellina fabula	2·5	7·5	1·02	1·39
Natica poliana	4·1	5·0	2·20	0·85
Scolelepis ciliata	3·3	8·3	1·65	1·50
Amphipoda	11·1	10·6	6·29	1·94
Echinocardium cordatum juves	1·3	4·0	0·51	0·76

(b) Cruise XV, 1953

	Number per 0·2 m².				Number pr. litre			
	Petersen	van Veen			Petersen	van Veen		
		chain	warps and guards	warps		chain	warps and guards	warps
Average volume (l.)	1·10	6·20	8·60	9·00	1·10	6·20	8·60	9·00
Species:—								
Ensis ensis	0·2	3·2	2·4	5·6	0·20	0·56	0·28	0·62
Tellina fabula	3·8	22·0	27·4	34·6	3·46	3·58	3·20	3·86
Scolelepis ciliata	3·4	19·6	27·4	26·4	3·26	3·10	3·26	2·90
Spio filicornis	0·8	7·2	4·6	12·2	0·80	1·22	0·52	1·34
Magelona papillicornis	2·2	21·2	28·6	21·0	1·80	3·56	3·33	2·33
Amphipoda	2·8	13·0	15·4	19·4	2·54	2·24	1·82	2·14
Echinocardium cordatum juves	1·8	2·6	1·6	2·8	1·60	0·40	0·18	0·30

Table 2 summarizes the comparison between the results obtained by expression of the densities per unit area and per unit volume. It shows that the difference between them can apparently be eliminated or even reversed when volume densities are used, although the Petersen grab is comparatively inefficient. However, it may be recalled that the depth at which an animal lives may depend upon its age (or size), and I have therefore inspected the data for any indication of differential capture of various age-groups. The data for *Tellina fabula* are instructive. Figure 5 shows the maximum length of *Tellina fabula* caught in each haul, plotted against the volume of the sample, and shows quite clearly that the Petersen grab (1–1·5 l.) caught no *Tellina* larger than 9 mm. whereas an increasing proportion of larger specimens, up to 15 mm., was caught in the deeper hauls. I have never caught a living *Tellina fabula* over 20 mm. in length, in more than 2,000 samples; but dead shells of up to 25 mm. are of quite frequent occurrence, which must mean that the oldest *Tellina fabula* lie too deep to be sampled by the conventional types of instruments. In this connexion it is extremely interesting to recall that DAVIS (1923) caught *Tellina fabula* from 2 to only 10 mm. in length, except for a single specimen of 12 mm.

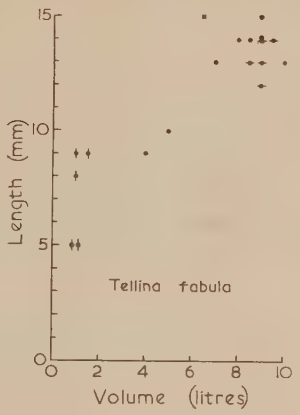

Figure 5. Maximum length of *Tellina fabula* plotted against volume of soil (in litres). Observations with the Petersen grab are indicated by a vertical bar (⊕), those with the van Veen with warps by a horizontal bar (⊖). Remaining observations were with the van Veen with chains, or with side-plates.

Summary

As a working basis for the comparison of samples obtained with either the same or different bottom samplers, expression of density per unit volume rather than per unit surface area is suggested. To express densities per unit area requires a knowledge of the depth of the stratum which each species occupies, and even penetration by the instrument at all depths. In fact, neither of these conditions can yet be attained. It is found that burrowing to greater depth with increasing age can lead to the complete escape from capture of the oldest individuals, which thus upsets the observed age-structure of the populations. The efficiency of horizontally pivoted instruments is seen to be rather low, the measured volume ranging from 41·4% to 69·3% of the expected volume in the series of samples presented.

Acknowledgement

I am grateful to Dr. J. Vervey, Director of the Zoological Station at Den Helder, for the loan of one of his grabs which demonstrated to me the advantages of operating the grab by warp.

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The World's Southernmost Indigenous Cod

By

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Introduction

The shoal waters to the south-east of Nantucket Island, bounded on the south by the 41st parallel of latitude, have long been tacitly considered the limit of the year-round distribution of the cod, *Gadus callarias* L., in the north-western Atlantic.

Dambeck (1879), Goode (1888), Tåning (1953), and Qasim (1956) have taken Cape Hatteras, N.C., at 35°10′N., as the extreme southern limit, although catches during the winter of 1926-27 were reported from Cape Lookout, N.C., 34°34′N., by Hildebrand (1941). Authorities agree that all southern location records are based on winter distribution. There is a report (Leslie, 1883) of "acres of codfish" seen floating belly up between Cape Hatteras and Cape Henry about 1. June, but the hearsay evidence presented is at best doubtful.

Recent catch statistics show that about five per cent. of the total United States catch of cod is taken in the Middle Atlantic and Chesapeake fisheries during the colder months of the year. Of the five per cent., the greater part, about 4·9 %, is taken in the waters off the Middle Atlantic states of New York, New Jersey, and Delaware, and only negligible amounts in the Chesapeake states of Maryland and Virginia. During the summer months, according to fishermen's accounts, only rare stragglers are caught in any of these areas.

Bigelow and Schroeder (1953) hold that cod found to the south and west of Nantucket in winter are migrants from southern New England, and Schroeder (1930) considers a large part of them migrants from Nantucket Shoals which return to home grounds during the summer.

But certain unanswered questions have been raised by these same investigators concerning the rationale of the seasonal distribution of these cod. Schroeder was unable to find a plausible stimulus for what he interpreted as the annual winter migration to the south-west; he carefully considered water temperature, spawning, food supply, food competition, etc., but rejected each. He also dismissed the possibility of random spreading due to lack of temperature barriers in the winter, since no corroborating similar movements to the north or east can be demonstrated. Bigelow (1956) comments that "half" the fish on Nantucket Shoals move to the Long Island and New Jersey coasts in the autumn, although conditions at one end of the range are not demonstrably different from those at the other end.

Tagging Experiments

Pertinent tagging experiments to 1930

SMITH (1902) reported on 4,019 cod tagged and released in the vicinity of Woods Hole around the end of January during the years 1898–1901. These fish were captured near Nantucket in October and November, held as a source of eggs and milt for the Woods Hole hatchery, and released in the spent condition. Numbered pieces of sheet copper were secured with copper wire at various places on the fish. Returns averaged about 3·5%, coming from the Cape Cod–Nantucket area in the summer and from as far away as the New Jersey coast in the winter. No authenticated recoveries were reported north of Cape Cod.

SCHROEDER (1930) tagged nearly twenty-five thousand cod from the US Bureau of Fisheries vessels "Halcyon" and Albatross II" on Nantucket Shoals during the summers of 1923–29. Unfortunately, the mark used, a metal strap attached to the caudal peduncle, is easily lost by the fish and returns were low, about 3%. The recapture locations were generally similar to SMITH's with an occasional straggler returned from considerable distances to the north and east. In addition, he repeated SMITH's experiment, tagging 1859 fish at Woods Hole, with essentially similar results.

SCHROEDER also tagged an additional 746 cod during the winter of 1928–29 off the southern New Jersey coast. Fifteen recoveries were reported (SCHROEDER, 1930) and they are considered below.

Recent tagging experiment

We tagged 448 cod off southern New Jersey during the winter of 1955–56. The mark used is a Lea hydrostatic capsule (ROUNSEFELL and EVERHART, 1953) attached to a Monel chain which is in turn fastened to the centre of a plastic tab about $1\frac{3}{4}$ in. long by $\frac{1}{2}$ in. wide. The tags were fixed to the fish by making a small incision in the flank with a recurved scalpel blade and inserting the tab into the coelom, where it serves as an internal anchor for the Lea capsule. Tank tests at Woods Hole suggested no mortality on cod over 25 cm. in length. The incision heals rapidly around the chain and no toxic or deleterious effects have been observed on experimental or recaptured fish.

Fifty-three (nearly 12%) of the marked fish have been recaptured in the first seventeen months following tagging[1]).

Tag returns

Figure 1 shows return locations from SCHROEDER's New Jersey work and from the current tagging experiment plotted for the winter months, December-March, the transitional months, October-November and April-May, and the summer months, June-September. It is apparent that cod tagged off the New

[1]) Exact dates and locations of tagging and recapture are filed in the Council's offices in Copenhagen and may be obtained from there, or from the author, on request.

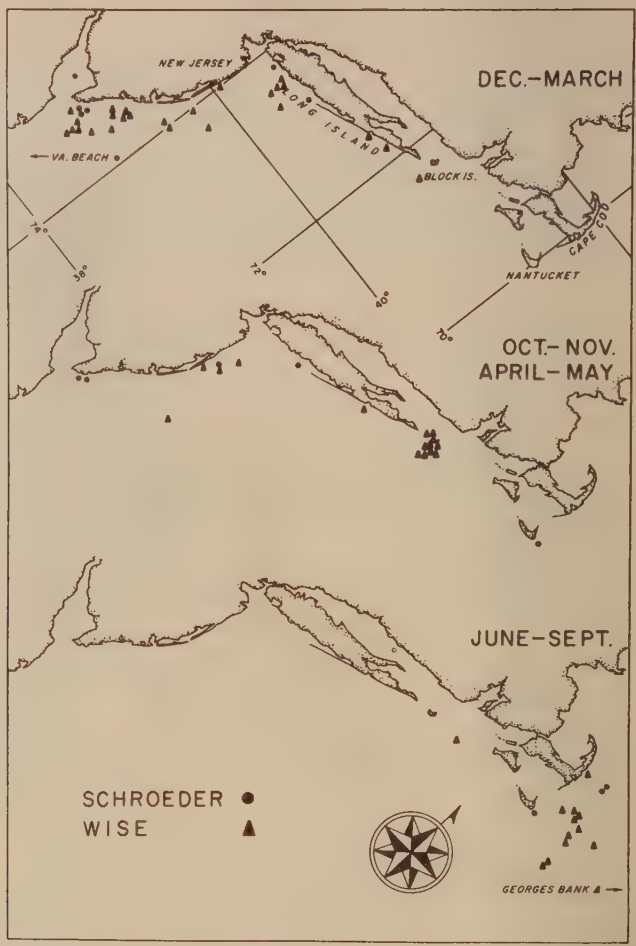

Figure 1. Locations of recaptures of cod from SCHROEDER (1930) and the current experiment. All fish were tagged off southern New Jersey in winter.

Jersey coast in winter are found north-east of Block Island only in the summer months (with a single exception in early October). During the winter they are concentrated on the New Jersey coast, and in the transitional periods they range from southern New Jersey to Block Island.

SMITH's results supported by SCHROEDER's repetition of the experiment show that some fish caught on Nantucket Shoals in October or November and released in January were found to the south-west during the winter, but we feel that cod after having been held for several months in live cars and stripped of eggs and milt cannot be expected to demonstrate reliable or completely normal patterns of behaviour immediately thereafter.

Conclusions

It may be seen, then, that it is possibly more appropriate and consistent with the facts gathered from tagging experiments to consider those fish found ranging from Nantucket Shoals to North Carolina as a separate group, at least partially independent from the southern New England cod with which they mingle in the warm months.

Discussion

This concept suggests an answer to at least one question previously raised. The autumn movement from Nantucket to the south-west is not a migration of part of the native fish in this direction, but rather a return of the Middle Atlantic cod to their native grounds after estivation in southern New England waters.

We saw ripe cod during the tagging work in 1956 off the New Jersey coast, and both SMITH and SCHROEDER mention the occurrence of these spawners. SCHROEDER also reports the finding of cod eggs and larvae by O. E. SETTE as far south as North Carolina. Therefore it is likely that this Middle Atlantic stock is not dependent on any other cod for recruitment, and that the return to native grounds in the winter is a spawning migration.

The proposed recognition of the Middle Atlantic cod as a discrete unit does not answer all the questions — rather it calls for a re-orientation, and examination of several important questions.

What stimulus initiates the movement to New England in late winter and early spring? What is the fate of the eggs and larvae which are carried further down the Atlantic coast by the general south-westerly drift (MILLER, 1952) prevalent in the spawning area? Further work on these and other problems may shed light on many aspects of a population which lives on the extreme fringe of the range of the species. Water temperature records may well furnish important clues here.

None the less, the seasonal movements fall generally into place, and this must be recognized as one of the wide ranging stocks of cod, comparable to the Lofoten cod of Norway. These North American cod also return annually to their home grounds to spawn.

An important difference, however, is that this appears to be the world's southernmost indigenous group of the species, spawning and spending most of its year between the 35th and 41st parallels of latitude, the latitudes of Portugal and North Africa in the eastern North Atlantic and of California in the Pacific.

Synopsis

The results of tagging experiments conducted by W. C. SCHROEDER in the winter of 1928–29 and the author in the winter of 1955–56 off the southern New Jersey coast of the United States have been analysed and show that cod thus tagged are found north-east of Block Island only in the summer months. During the winter these fish are concentrated on the New Jersey coast, and in the transitional periods they range from southern New Jersey to Block Island.

On the basis of this analysis it is proposed to recognize the cod which roam from Nantucket Shoals to North Carolina as a discrete group, indigenous to this area. This, then, is the southernmost unit of the species.

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Reactions of Fish to Artificial Light, with Special Reference to Large Herring and Spring Herring in Norway

By

Olav Dragesund

Introduction

It is well known that some species of pelagic fish, such as herring, mackerel, sprat, anchovy, and sardine, can sometimes be aggregated and drawn towards the surface by artificial light. This behaviour response has been utilized by fishermen in some countries, and lights are used as part of the fishing equipment. In Norway this is the case in the purse-seine fishery for herring.

Experiments with submerged electric lights were carried out in the Norwegian fishery for spring herring as early as 1885, but gave no positive results, and it was not until about 1930 that lights gradually became part of the purse-seiner's equipment. Today lights are used by both purse-seiners and shore-seiners during the winter-herring fishery, and they are also extensively used in the other herring fisheries along the Norwegian coast.

Several experiments have been carried out in aquaria to study the response of different species of fish to light. FRANZ (1913) showed that the reactions of the fish depend on the surroundings and the size of the aquarium. Experiments made with larvae of both pelagic and semi-pelagic fish species showed that positive phototaxis occurred with unusual stimuli and signs of danger ("Phototaxis als Fluchtbewegung").

Experiments carried out by KAWAMOTO and TAKEDA (1951) showed that the "gathering rate" around the light was influenced by the wave-length of the light. The fish were attracted most strongly by green and blue light, and wave-length was of greater importance than intensity. Later experiments by KAWAMOTO and KONISHI (1952) showed, however, that the "gathering rate" of the fish was highest around the strongest light. Nevertheless, there was no doubt that "gathering rate" also depended on wave-length. KAWAMOTO and NAGATA (1952) then studied the behaviour of fish to different light gradients. The behaviour of some fish species by day was found to differ from that by night.

Although experiments in aquaria have their value in certain studies, they do not indicate how the fish would have behaved in the sea. MAEDA (1951)

examined the community of animals attracted by a light lowered into the water or held just above the sea surface. He found that fish, as well as squids and crayfish, were attracted by the light. These experiments were carried out in shallow water, and MAEDA was therefore able to observe the behaviour of the groups visually. In deeper water, observations on the behaviour of fish can be made by means of the echo-sounder. Such experiments were carried out by KREFFT and SCHUBERT (1950). These showed that fish could be aggregated by illuminating the surface of the water. Whether this movement was a direct response to the light, or whether the fish followed the plankton was not decided. The fish attracted to the light were mainly whiting, but herring and mackerel were also seen. SCHÜLER and KREFFT (1951) conducted similar experiments the following year, but these showed, on the contrary, that the herring descended as soon as the light was switched on, and returned to their former level when the light was switched off. Experiments carried out by RICHARDSON (1952) off the coasts of East Anglia and Yorkshire, and off Cape Gris Nez, also showed that the herring avoided the light. BLAXTER and PARRISH, using an underwater source of light off the Scottish coast, aggregated mainly whiting and young clupeoids. They studied the vertical migration in response to artificial light, the extent of the aggregation, and the possibility of catching the fish (verbal communication).

Ultraviolet light was used in experiments carried out by CRAIG and BAXTER (1952) on the east coast of Scotland.

Summarizing the results of the papers mentioned above, we may conclude that artificial light does not always attract fish. Nevertheless, light may draw them towards the surface in such abundance that fishermen can take advantage of this behaviour in practice.

The problems which are dealt with in this paper are as follows:—

1. Does artificial light always cause herring to collect together?
2. Are herring drawn nearer to the surface by illuminating the sea surface?
3. If so, are the movements directly provoked by the light?

The Use of Lights in the Norwegian Herring Fishery

Most of the Norwegian purse-seiners are equipped with a 10–16 kW. (110 volts) DC generator, which supplies from 3 to 6 searchlights of 1–3 kW. power. These are usually set up on stands on the wheel-house and the stern of the vessel.

Before the searchlights are switched on, the vessel surveys the fishing ground and the echo-sounder is run continuously. If a herring shoal is observed, the vessel is anchored over the shoal, the engine is stopped, and the light switched on, illuminating the sea surface obliquely. The echo-sounder is not run continuously when the light is on, but is switched on and off alternately. The fishing-master on board the "flag-ship" tracks the herring, while the boats are lying ready to shoot the purse-seine. Sometimes the herring enter the zone of light after a few minutes, but at other times it may be several hours before they do so, and on occasions the herring do not appear at all.

The purse-seiners sometimes use their lights without having seen herring shoals beforehand. The vessels are then anchored on grounds where herring are usually found. It is usual to anchor in a depth of about 50 m.

Because the herring seem to be shy of noise while they are collecting round the light, the generator is often placed on rubber pads, to diminish the sound transmitted to the hull. The reaction of the herring to the lights also depends to some extent on the weather. Cloudy, mild nights are better than bright, cold ones. Most of the fishermen maintain that the light should be diffused when the sea is calm, and concentrated by reflectors when the surface is broken.

The most general opinion held by fishermen is that the light causes the herring to draw together and rise towards the surface. They do not, however, always move to that part of the illuminated zone in which the light intensity is highest, but often aggregate on the border of the cone of light or just outside it. There are fishermen who believe that the behaviour of the herring towards light varies, and that it is difficult to lay down any hard and fast rules on the matter.

Investigations

In October and November 1952 two cruises were undertaken in Oslofjord to study the behaviour of the sprat in relation to light. The main part of the investigation, however, was carried out on the herring grounds on the west coast of Norway in winter 1953. The M/S "Gunnar Knudsen", belonging to the Institute of Marine Biology, University of Oslo, was commissioned for the cruises.

Apparatus and methods

The apparatus used in the experiments consisted of a searchlight with a 1500 W. projector. The lamp was attached to a spar, which could be turned outboard. A photometer was used for studying the light penetration. By means of colour filters it was also possible to measure the penetration of light of different wave-lengths. The intensity of the light at different depths is stated as a percentage of that at the surface. These relative values give a rough indication of the penetration of the light, and also of the transparency of the water.

The behaviour of the fish shoals was recorded on a SIMRAD echo-sounder, which was equipped on this occasion with a special transducer, mounted on the ships rail. This transducer could be operated from the deck, and a search could be made through 360° at a slight angle to the horizontal. This instrument was designed by Simonsen Radio Ltd., and was the forerunner of the "fishery asdic" later constructed by the firm.

Investigations in Oslofjord

The experiments were undertaken on 20. and 21. October and 13. and 14. November 1952. It was not proved that the fish recorded with the echo-sounder were sprat, but it is probable that they were, as sprat were caught by fishermen in the same area.

Cruise I. Figure 1 shows diagramatically the top of the shoals during the experiments, with depth as ordinate and time as abscissa. The times at which the light was on or off are indicated on the horizontal scale.

By day the shoals at Sta. V.1 (Figure 1) were at a level about 10 m. higher than at Sta. V.2. Towards sunset, the shoals at Sta. V.2 began to move upwards

Sprat = Clupea sprattus

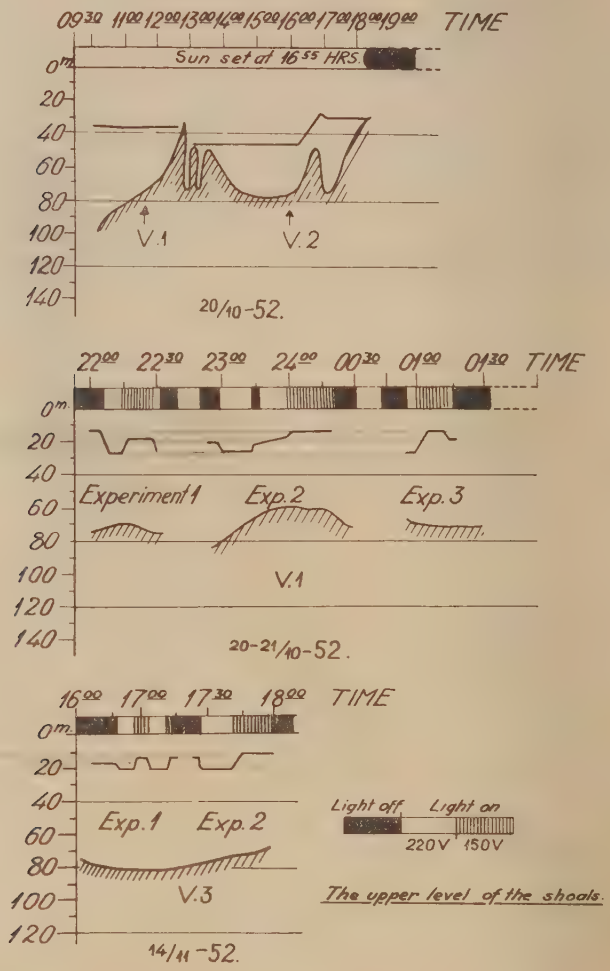

Figure 1. Showing the level of the top of the shoal during the experiments. The time at which the light was switched on and off is indicated on the linear scale.

Figure 2. Echo-gram from experiment at Sta. V.1. The plankton net used is shown in the echo-gram.

and rose 15 m. in 45 min. It was also noticed that the shoals were less concentrated by night than by day.

On the first cruise three experiments were carried out at Sta. V.1. All the experiments showed that as soon as the light was switched on, the top of the shoals descended and the shoals became denser. During the second and third experiments, fish were definitely aggregated by the light, and when the voltage was reduced from

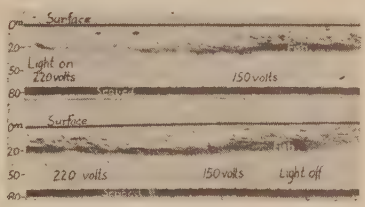

Figure 3. Echo-gram from the first experiment at Sta. V.3.

Table 1

Vertical plankton hauls 0 to 30 m. at Sta. V. 1

	Numbers of copepods	
	Before the experiment	During the experiment Voltage 150 v.
Calanus finmarchicus	669	154
Microcalanus sp.	1	1
Oithona sp.	–	1
Podon sp.	5	6
Evadne sp.	2	–
Sagitta sp.	3	14
Lensia conoidea	2	–
Eudoxie	7	6
Appendicularia	1	8
Philalidium hemisphericum	1	3

220 v. to 150 v., the shoals gradually rose from 28 m. to 15 m., the top of the shoals having been at 25 m. beneath the surface before the light was switched on. As soon as the light was switched off, the shoals gradually became less dense and descended to their former level (Figures 1 and 2).

Vertical plankton hauls were made before and during the third experiment. The plankton in both hauls consisted mainly of *Calanus finmarchicus* (Table 1), but since the mesh of the net was rather coarse (silk No. 8 in the cone), smaller species might have escaped. Table 1 shows that the concentration of *Calanus finmarchicus* was greatest before the experiment began. The experiments were finished at 0130 hours. At 0645 hours fish were again recorded in the same locality, the top of the shoal being at a depth of 28 m. At dawn the shoal gradually descended and at 0820 hours its top was at 45 m.

Cruise II. On the second cruise two experiments were carried out at Sta. V.3, and in both cases fish were aggregated by the light (Figures 1 and 3), but positive phototaxis was not so apparent during the second experiment as during the first. On this occasion a greater aggregation was obtained when the light was switched on. It is possible that the upper markings on the echo-gram are due to a species other than that responsible for the tracings below, possibly *Gasteorosteus aculeatus* L., as these fish could be seen close to the surface during the experiment.

Just before and during the first experiment vertical hauls were made for plankton, which consisted mainly of *Oncea* sp., *Oithona* sp., and copepodites of *Pseudocalanus* sp. and *Paracalanus* sp. The plankton shoals were slightly denser when the light was on than when it was off (Table 2).

Table 2

Vertical plankton hauls 0 to 30 m. at Sta. V. 3

	Numbers of copepods	
	Before the experiment	During the experiment Voltage 220 v.
Calanus finmarchicus	13	3
Microcalanus sp.	4	4
Pseudocalanus sp.	138	168
Paracalanus sp.	–	–
Temora longicornis	3	10
Centropages sp.	–	3
Oithona sp.	226	269
Oncea borealis	93	159
Evadne sp.	1	1
Sagitta sp.	1	3

Investigations in the Large-Herring and Spring-Herring Districts, West Coast of Norway

Large herring

The "Gunnar Knudsen" reached the fishing grounds on 30. January, and three experiments were carried out near Florö during the fishery for large herring between the end of January and the middle of February. Samples taken from drifters fishing in the vicinity showed that the herring present were pre-spawners in maturity stage V.

Artificial lights are not much used by commercial fishermen during the large herring season, but occasionally purse-seiners succeed in aggregating the herring by this means.

At Sta. H on 5. February a shoal was observed to rise from 40 m. at 1500 hours to 20 m. in about an hour. Just after sunset the herring descended to between 30 and 50 m., where they remained during the night. At about 1900 hours another herring shoal was recorded at Sta. N, the top of which was 30 m. below the sea surface. The light was switched on at 1910 hours and an immediate reaction was visible on the echo-chart, the fish appearing like a cloud rising towards the surface. Airbubbles in the water also indicated the sudden upward movement of the herring (Figure 4).

After 2 or 3 minutes the cloud disappeared and the shoal, now more densely packed, descended until the top reached 50 m. depth. At 1915 hours the voltage was lowered from 220 v. to 150 v. and the herring at once rose 10 m. After a few minutes the light was switched off, and in the course of 3 or 4 minutes the shoal rose 30 m., the level at which it was first recorded. The first reaction might be a shock effect due to the light being switched on.

The following morning herring were again recorded in the same position. At 0700 hours the top of the shoal was at 40–50 m. depth. After sunrise, at 0850 hours, the herring were 80–90 m. below the surface. No echo-sounder records were made during daylight, but in the evening the second experiment was carried out (Figure 5). The herring, at 30 m., reacted by packing and descending when the light was switched on; the shock effect resulting in movement towards the light, however, did not occur. The herring seemed to become gradually accustomed to the light, and after 12–15 minutes they again rose to 35 m. When the voltage was dropped from 220 v. to 150 v., they immediately rose a further 5 m., and remained at a depth of 30 m. until the

voltage was raised to 220 v. They then descended to 40 m., but thereafter their behaviour changed as they gradually rose towards the surface, and the traces became more diffuse. The shoal remained in this condition for three quarters of an hour, the top sometimes being only 10 m. from the surface, and it would have been possible to catch them with a purse-seine. At 2025 hours the light was switched off, whereupon the herring gradually packed together and descended to 30 m., the depth at which they were when the experiment started.

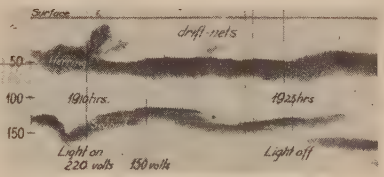

Figure 4. Echo-gram showing the shock effect. The herring rose like a cloud towards the surface immediately the light was switched on. After 2 or 3 minutes the cloud disappeared and the herring packed themselves more densely together and descended.

A third experiment was carried out six days later (13. February) at Sta. F. Throughout the day no herring were observed in the fjord, but a large number of diffuse shoals were recorded after sunset at a depth of 30 m. As soon as the light was switched on, the shoals packed closer and descended. Records taken with the special transducer showed that the herring were deepest immediately below the light source where the intensity was highest. Figure 6 shows diagramatically the distribution of the herring while the light was on. The searchlight was kept on over the shoal for 4 hours, and during this time the fish remained at about the same level.

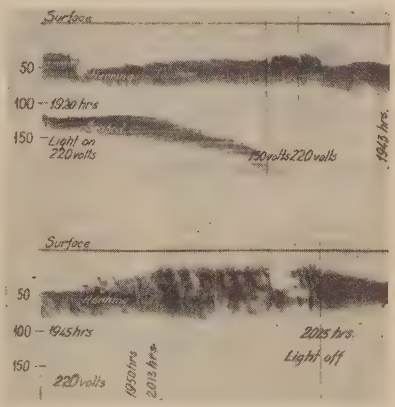

Figure 5. The second experiment at Sta. H. The herring reacted by packing and descending when the light was switched on. After a while, the herring seemed to become gradually accustomed to the light, and eventually shoaled and rose towards the surface.

Vertical plankton hauls were made in order to determine the concentration of plankton before and during the experiment. The catches, which were small, consisted mainly of *Oithona* sp. and small calanoids. The concentration was a little greater during the experiment than beforehand.

The vessel lay over the herring shoals throughout the night and early morning. Occasionally the light was switched on and off, with the same effect on the herring as before. At dawn the herring gradually concentrated in a number of denser shoals, which descended as daylight increased. No upward movement just before sunrise was observed (Figure 7).

Spring herring

Three experiments were carried out at Sta. S.2 (28. February, 1. and 2. March), near Skudesnes, on the southern part of the herring grounds. The conditions for work were not of the best, due to the difficulty in surveying the area where several purse-seiners were working. Furthermore, the concentrations of herring were small.

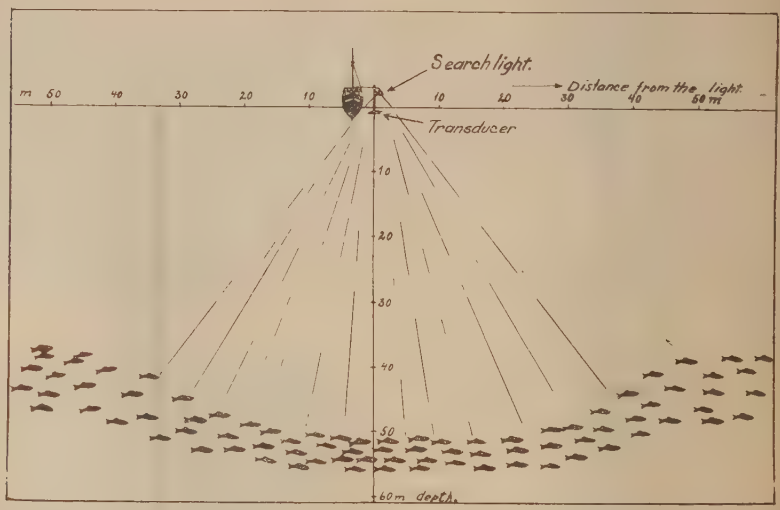

Figure 6. Showing the distribution of the herring during the experiment at Sta. F while the light was on. The herring were evidently affected by the light within a radius of about 50 m. from the source.

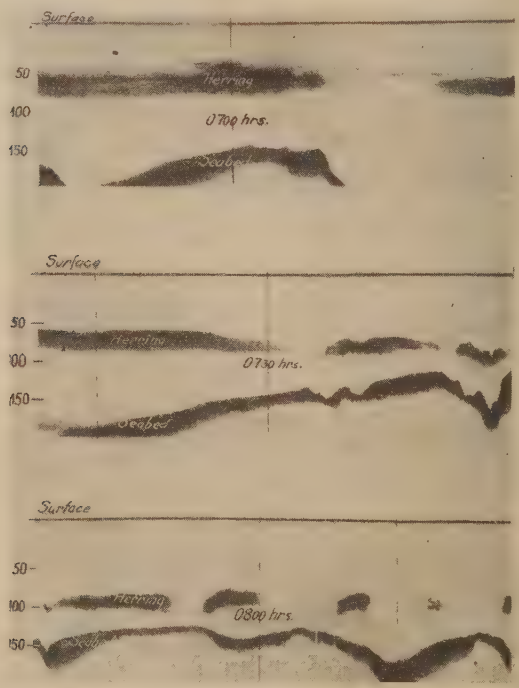

Figure 7. Records made at Sta. F at dawn. The herring gradually separated into relatively dense shoals, and descended as daylight increased.

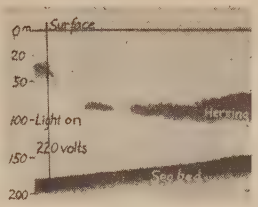

Figure 8. Records obtained during the third experiment at Sta. S.1. When the light was switched on the herring packed together and descended.

The diurnal migration was rather difficult to detect, although our experience is that such movement is to be expected during the spawning season as well as at other times. Immediately before spawning, the herring settle near the bottom, and in the first and second light experiments, the herring were in fact recorded just above the sea-bed before the light was switched on. As soon as it was switched on, the herring reacted by packing close to the bottom.Towards the end of the experiments the light was switched on and off several times, and once in each experiment the traces showed the shock effect, as observed at Sta. H (Figure 4).

When the third experiment began at 1930 hours, the shoals were observed at 30 m. from the surface. As soon as the light was switched on, the herring descended until the top of the shoal was at 70 m. When the voltage was lowered from 220 to 150 v., the herring gradually closed in and rose to 50 or 60 m., where they remained (Figure 8). At 2015 hours the light was switched off and 35 minutes later it was switched on again; once more the shock effect followed, the herring gradually moving away from the light source.

Observations made with the special transducer during the third experiment showed that the difference between the levels of the herring inside and outside the cone of light was fairly sharp. The experiments indicated no difference between the behaviour of the spring herring and that of the large herring. However, spawning had not quite started at the time of the experiments, which took place at full moon, and the reactions of the herring might have been determined by this circumstance.

Discussion and Conclusions

Observations showed that on both cruises in Oslofjord the fish were deepest in those localities at which sunlight penetrated furthest.

It may be seen in Figure 9 that the penetration of total sunlight (measured without a colour filter) was the same in the upper 10 m. at both Sta. V.1 and Sta. V.2 on the first cruise. Below this level the penetration was a little greater at Sta. V.2. This applied also to the green component. The red and blue components, on the other hand, showed rather more penetration at Sta. V.1 than at V.2 at depths greater than 10 m. The fish at Sta. V.1 were at 35 m., and at Sta. V.2, at 45 m., at approximately the same time. All components of the sunlight at Sta. V.2 on the second cruise penetrated further than on the first (Figure 9), and the fish were found at 55 m.

Figure 10 shows the depth of the top of the shoal at Stas. V.1 and V.2 on the first cruise and the depth corresponding to value 1 on the photometer plotted against time. The fish began to rise when the light intensity decreased, but the upward movement lagged behind the alteration in intensity.

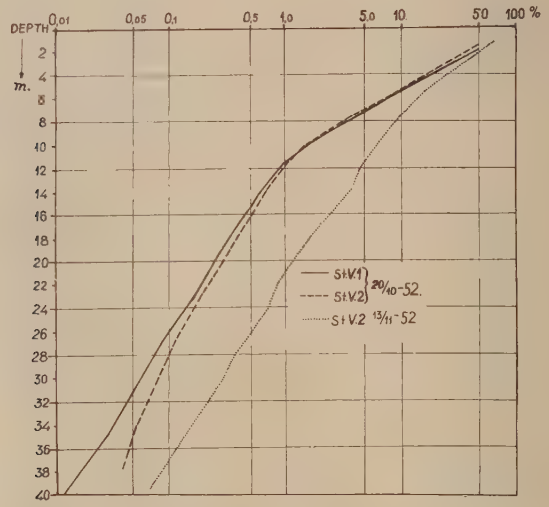

Figure 9. The penetration of sunlight at Stas. V.1 and V.2 on the cruises in Oslofjord.

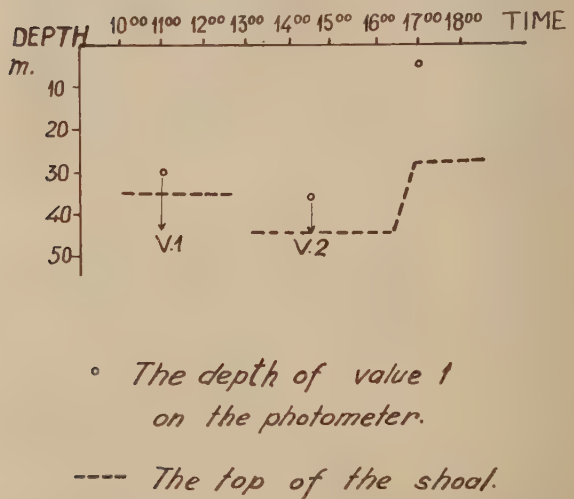

Figure 10. Showing the depth of the top of the shoal in Oslofjord and the depth corresponding to value 1 on the photometer.

Table 3

Relationship between the depth of the shoals during the light experiment, and the depth of the 0.1 % light-level

	Depth of the herring m.	Depth of the 0.1 % light-level (artificial light 220 v.) m.
Sta. H Experiment 1	50–60	17
– F	60–80	21
– S.2 Experiment 3	70–80	21

The diurnal movement of the herring on the west coast of Norway was hard to distinguish precisely, but the few observations made seem to correspond with those of RICHARDSON (1952), who found a diurnal migration of the herring in the North Sea, the herring rising gradually to the surface at night and descending during the day. The level at which the shoals remained during the night appeared to be definite, but an upward movement, above that of the normal level at night, was seen at dusk before the shoals settled to the usual level. RICHARDSON also found a similar upward movement at dawn, which preceeded a downward movement associated with increasing light intensity. This upward movement at dawn, however, was not observed on the west coast of Norway.

Under the influence of artificial light the fish usually seemed to behave as expected. When the light intensity was increased, they descended and packed together, which is also a normal response to increase in intensity of daylight. Sometimes, however, they showed a different reaction; they packed together and rose towards the light, which seemed to be the direct cause of this behaviour.

The echo-grams taken in Oslofjord and on the west coast of Norway during the light experiments show that the fish do not always react in the same manner to the switching on of the light, and four different types of reactions can be distinguished:—

1. The fish descend and appear to pack together (Figure 8).
2. The fish scatter and the shoal gradually disappears.
3. The fish make a sudden upward movement the moment light is switched on, but after 2 or 3 minutes disappear or descend (Figure 4).
4. The fish pack together and rise towards the surface (Figures 3 and 5).

More than one of the four types of reaction may be observed in a single experiment.

As regards the first type of reaction, which was frequently recorded both in Oslofjord and on the west coast of Norway, Table 3 indicates that a relationship exists between the depth to which the light penetrates and the depth at which the fish lie. This behaviour seems to be in accordance with the daylight observations. In Table 3 the depth of the shoals refers to a voltage of 220 v. It makes no difference to the depth of the shoal whether the current is immediately switched on at 220 v. or whether the voltage is raised from 150 to 220 v. The light measurements for both daylight and artificial light at Stas. H and F are shown in Figure 11. It may be noticed that sunlight penetrated further than the artificial light used. This might be due to the fact that the intensity of the sunlight at a given depth is increased by lateral diffusion.

The second type of reaction was observed several times both in Oslofjord and on the west coast. The third type, however, was only recorded on the

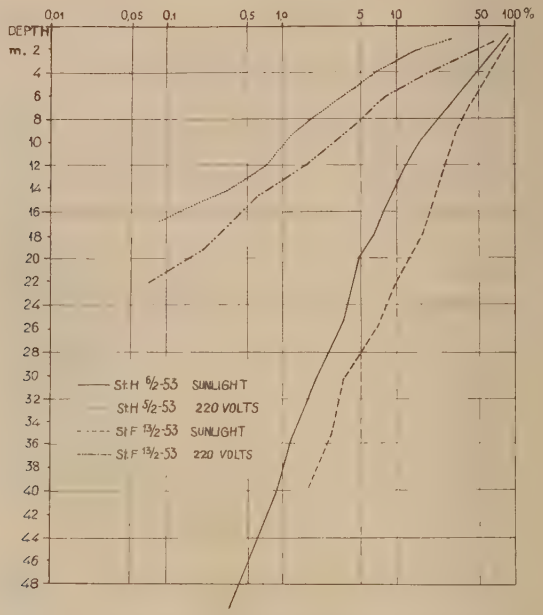

Figure 11. The penetration of sunlight and artificial light at Stas. H and F.

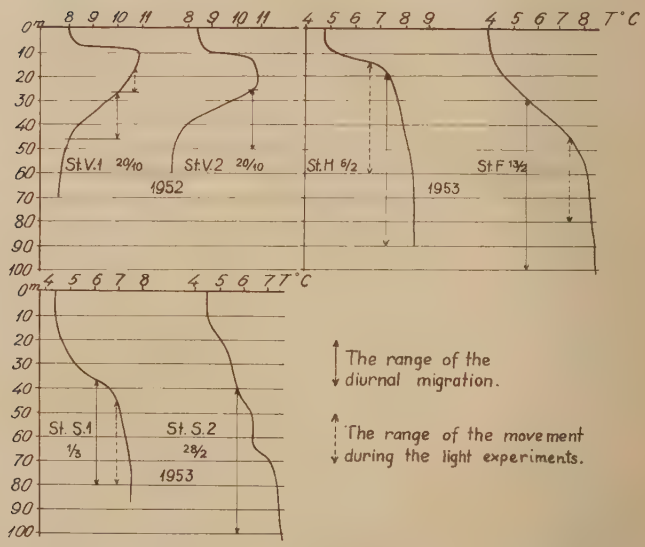

Figure 12. Showing the temperature at the different stations in Oslofjord and on the west coast. The ranges of the diurnal migrations and the movements during the light experiments are also shown.

west coast immediately after the light was switched on. In both cases the fish were probably frightened.

The fourth type of reaction is more difficult to understand. Plankton catches made at Sta. V.1, when this reaction occurred, do not show that the fish assembled in the light in order to feed, but further investigations must be undertaken before this possibility can be completely ruled out. An alternative interpretation is perhaps that the fish, after being stimulated by the light, gradually become panic-stricken and rise towards the light. This view is supported by the diffuse markings recorded during the second experiment at Sta. H (Figure 5). These appear to indicate a lively movement by the herring in the light. Experiments carried out by the author (unpublished) on fat herring in a purse seine also favour this theory. These herring became restless and started swimming rapidly in a circle when the light was switched on, but after a few minutes they appeared to pack together and move into the centre of the light cone. Experiments made by FRANZ (1913) in an aquarium also support this conception.

The hydrographical conditions were examined, in case they might have affected vertical migration. The range of the diurnal migration recorded on the first cruise in Oslofjord varied between 28 and 45 m. at Sta. V.1, and 28 and 52 m. at Sta. V.2. During the experiments, the depth varied between 15 and 27 m. As may be seen in Figure 12, the fish were always recorded below the upper thermocline, which was found at about 10 m. At dusk, however, the fish crossed the lower thermocline, in which a temperature difference of nearly 4°C. was present at Sta. V.2. This indicates that fairly large temperature gradients do not invariably prevent the vertical migrations of fish.

The range of the diurnal migration of large herring was 20 to 100 m. During the light experiments, the vertical range of the movement was 15 to 75 m. The herring were then found mostly below the thermocline (Figure 12, Stas. H and F). Only once (2nd experiment, Sta. H) did the herring pass through the thermocline. The spring herring were always recorded below the thermocline at Sta. S.1, except when the shock effect occurred. But even at Sta. S.2 (Figure 12), where no distinct thermocline was observed, the herring moved no nearer to the surface. In general the temperature gradients which the herring crossed on the west coast were smaller that in the case of the Oslofjord fish.

The difference in salinity between 20 and 100 m. were so small, both in Oslofjord and on the west coast, that they can hardly have had any influence on vertical movement (Table 4). In support of this assumption, I may refer to experiments made by BULL (1928) on *Blennius gattorugine*. When he used differences in salinity as conditioned stimuli and food as unconditioned stimuli, the fish showed no reaction to differences in salinity smaller than $3^0/_{00}$.

Acknowledgements

I wish to express my thanks to the Borgestad Legat I and to the With Endresen's Fond for the grants which made this work possible. Thanks are also due to the Simonsen Radio A/S, Forsvarets Forskningsinstitutt, and N/A Philips for placing equipment at my disposal. Further, I am much indebted to Professor Johan T. RUUD and Mr. B. B. PARRISH for their criticisms of this paper.

Table 4

Salinity (‰) at various depths

Stations	Depth m.	Salinity ‰
Sta. V.1	10	29·40
	25	30·81
	40	30·92
Sta. V.2	10	30·16
	25	31·46
	40	32·32
	60	32·39
Sta. H	10	32·32
	25	33·66
	40	34·55
	75	34·78
	100	35·07
Sta. S.1	10	33·37
	25	33·64
	40	33·84
	75	34·56

Summary

Light was first used in the Norwegian commercial herring fishing in about 1930, and today both purse- and shore-seiners use lights to attract herring, especially the spring herring. The purse-seiners are equipped with searchlights of 1 to 3 kW., which are switched on when the vessel is at anchor or drifting.

Experiments on the effect of artificial light on fish were carried out in Oslofjord and on the west coast of Norway. The fish observed in the former case were probably sprats, but in the latter case they were undoubtedly winter herring. For these experiments a 1.5 kW. searchlight was used, the strength of the light being changed by altering the voltage.

A photometer was used to measure the light intensity (for both daylight and artificial light). The instrument was not calibrated in absolute units and the light values given are therefore relative.

For observing the behaviour of the fish shoals, a Simrad echo-sounder was used, which on this occasion was equipped with a special transducer mounted on the ship's rail. This transducer could be controlled from on deck, which allowed a search to be made in all directions at a slight angle to the horizontal plane.

The fish shoals showed a diurnal migration, coming up towards the surface at night and moving down during the day.

Four types of reaction to light were observed:—

1. The fish packed together and descended.
2. The fish disappeared from the light.
3. The fish showed a sudden upward movement (shock effect) towards the light immediately it was switched on, but after a few minutes either disappeared or packed and descended.
4. The fish packed together and rose towards the light.

The fish reacted to artificial light in much the same way as to daylight

(1st type), though they sometimes showed an opposite reaction (4th type). The stimulus for this behaviour seemed to be the light.

The third type of reaction was only recorded in the west coast investigations. More than one of the four types might occur during a single experiment.

The hydrographical conditions below the thermocline seem to have had no influence on the behaviour of the fish, either in Oslofjord or on the west coast.

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On the Shape of Herring Schools

By

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Introduction

It is generally recognized by fishermen that the directions of wind and tidal stream have a definite bearing on the size of their catches, particularly in relation to pelagic fish. Catch is dependent on the efficiency of the gear used and on the presence of fish. Wind and stream, therefore, influence the catch through the effects they have both on the gear and on the fish. The effect of wind and stream on gear is well known. In a drift-net fishery the nets are shot down-wind and are carried over the ground by the tidal stream. Wind governs the orientation, and stream the movement of the nets.

The work to be described was undertaken to find out, firstly, the shape of a herring school under given conditions of place, time, and tidal stream, and secondly, the bearing which the shape of such a school has on drift-net fishing.

Method

The research vessel used in this work was fitted with a Kelvin-Hughes echo-sounder (MS 24), a Decca navigator, and a Decca track-plotter.

The track-plotter works in conjunction with the Decca navigator. The display unit of the track-plotter presents a paper scroll which is wound up and down vertically between two rollers. A pen traverses the paper horizontally, so that a continuous record of Deccameter readings is presented graphically in the form of a rectilinear grid. The components of this, expressed by the movements of pen and paper, comprise the two hyperbolic lattice lanes selected, e.g., red and green, red and purple, or purple and green. The actual geographic track made good by the vessel is found by translating the points of intersection of the lanes made by the pen on the plotter paper to the appropriate Decca chart.

In order to delineate the shape of the schools, the track-plotter was marked at the times of beginning and end of each trace recorded on the echo-sounder. When a trace was "lost", the practice, whenever possible, was to turn the vessel back into the direction in which traces were recorded.

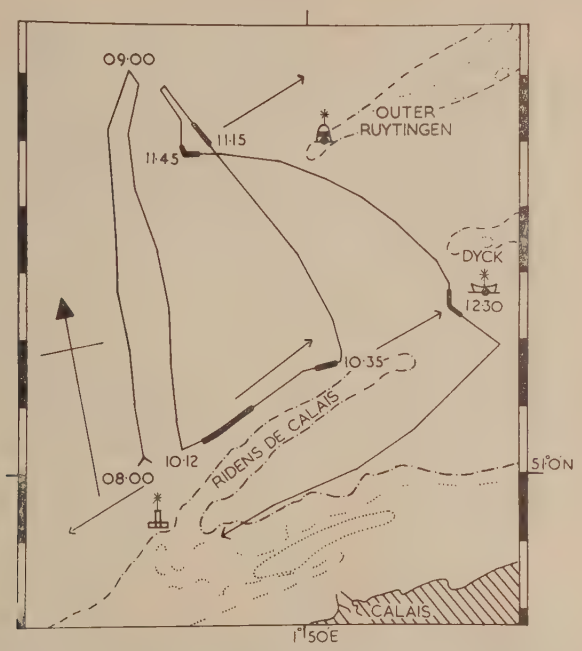

Figure 1. The track of an echo-search made across and in line with the tidal stream on 14. December 1955. Arrows denote the direction of the tidal steam at the times stated.

The observations were made in the English Channel between Calais and the Sandettié Bank during December 1955 and January 1956.

In all examples given, the traces were recorded when the tidal stream was running at or near its maximum speed. This was calculated from the tidal information given on the chart and the Admiralty Tide Tables.

The tracks made good as recorded on the track-plotter and translated to the Decca charts are given in Figures 1 to 4. In these, a *thin* line indicates that fish traces were *absent*, and a *thick* line that they were *present*.

Results

1. The alignment of traces with the tidal stream

The result of an echo-search made across and in line with the main direction of the tidal stream is shown in Figure 1. Traces recorded near the Outer Ruytingen (at 11·15 and 11·45 hours) and near the Ridens de Calais (at 10·12, 10·35, and 12·30 hours) suggest that the points where traces were recorded lay in line with the direction of the flow, and that if the traces were cross-sections of whole schools, the longest axes of the schools lay in line with the direction of the tidal stream.

Figures 2, 3, and 4 show the results of echo-surveys made over, apparently,

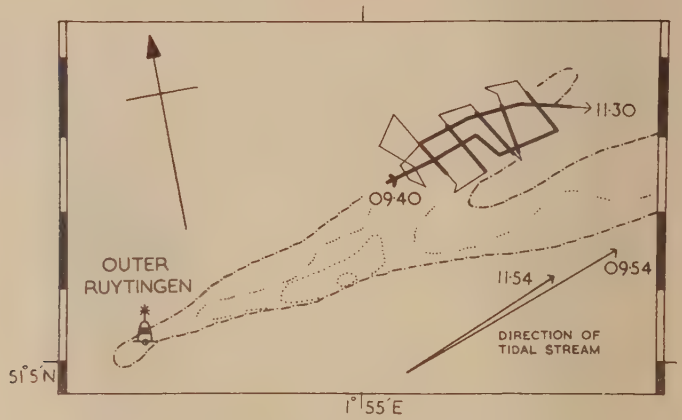

Figure 2. Track recorded in the Outer Ruytingen area on 11. December 1955.

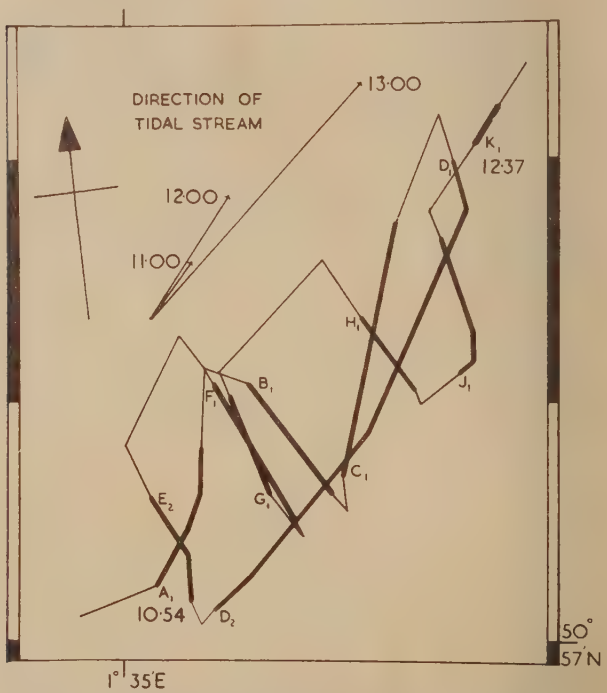

Figure 3. Track recorded in the vicinity of the "Overfalls" on 14. January 1956.

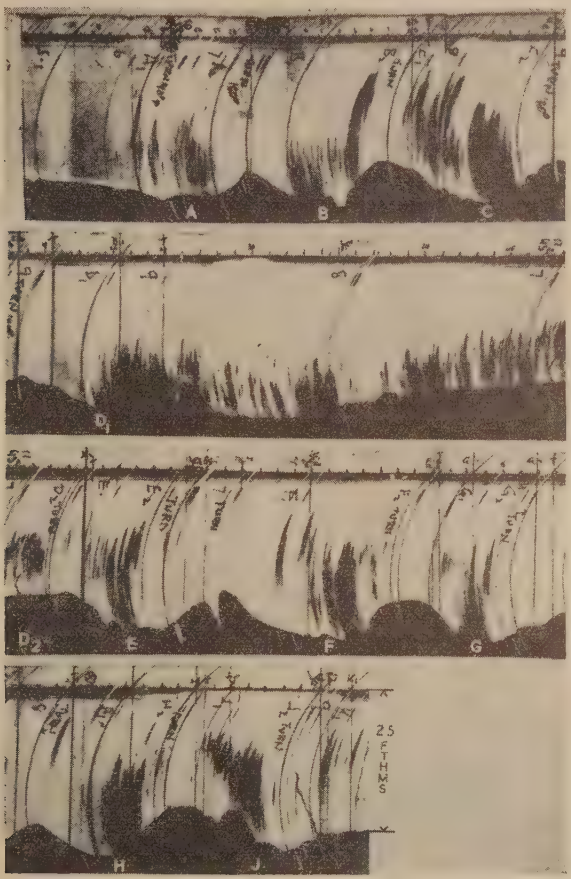

Figure 3a. Echo-sounder record relating to the track shown in Figure 3.

whole schools. During the periods of these surveys the tidal streams were running between N.N.E. and E.N.E.

Figure 2 shows the result of a survey of a school near the Outer Ruytingen Bank on 11. December 1955. The direction of the tidal stream was 060° at 09·54 hours and 057° at 11·54 hours.

Figures 3 and 4 show the results of surveys made in the area known as the Overfalls (6 miles N. × E. of Cape Gris Nez) on 14. January 1956. In Figure 3 the direction of the tidal stream at 11·00 hours is 033°; at 12·00 hours, 032°; and at 13·00 hours, 041°. In Figure 4 the direction at 14·00 hours is 045° and that at 15·00 hours is 042°.

In each of the Figures 2, 3, and 4 the track shows elongated shapes within the perimeters of recorded traces and in each case the traces which are parallel with the flow are longer than those which cross it.

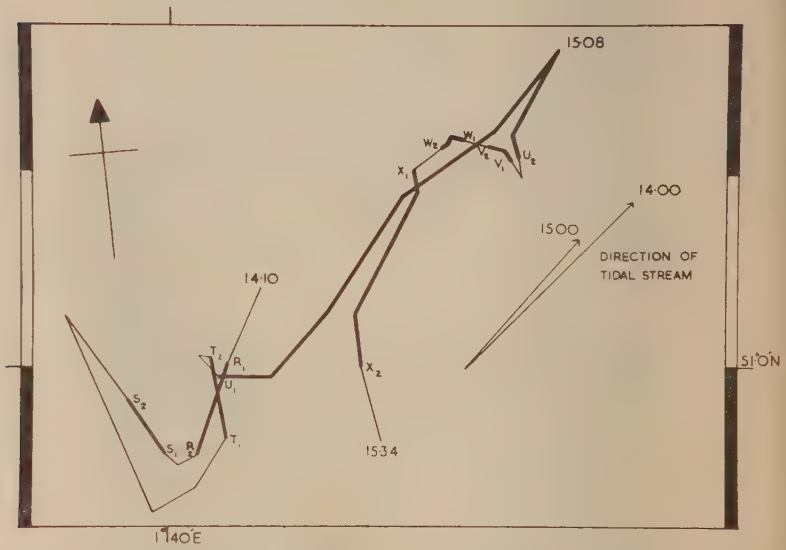

Figure 4. Track recorded in the vicinity of the "Overfalls" on 14. January 1956.

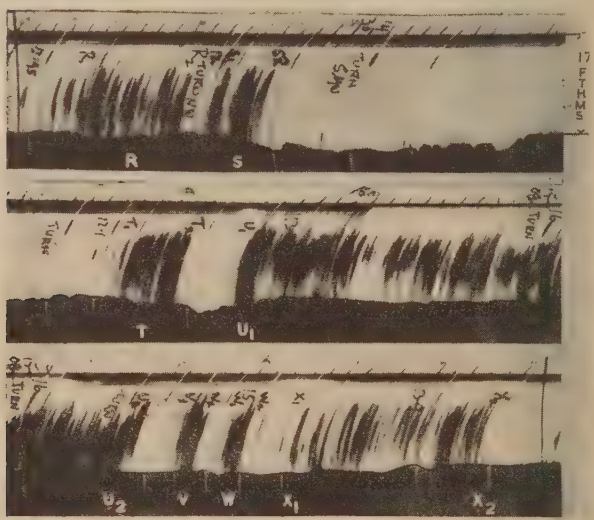

Figure 4a. Echo-sounder record relating to the track shown in Figure 4.

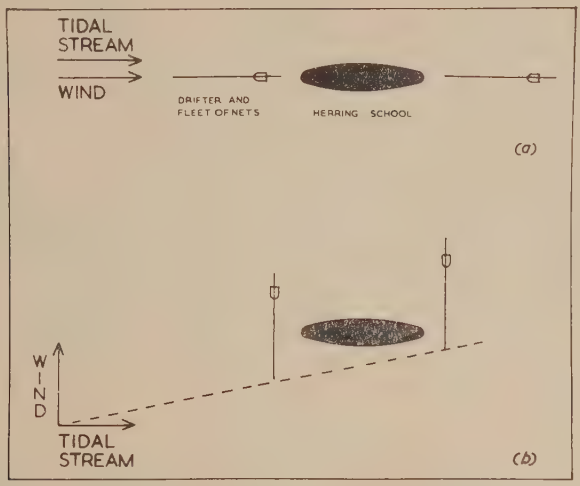

Figure 5. Diagram to show the location and movement of a fleet of drift-nets over a herring school relative to the direction of the wind and of the tidal stream.

2. The relation of traces to the sea bed

Figures 3a and 4a show the echo-sounder records of the sections plotted in Figures 3 and 4 respectively.

In Figure 3a the extensive record D_1–D_2 was made along the long axis of the school. The traces which were recorded when the ship crossed the direction of the tidal stream (B, E, F, G, H, and J) are shorter than those recorded when it moved in line with it (D) or obliquely across it (C). Examination of the contours of the sea bed shows that the school lay over a trough-like depression (see sections B_1–B_2, C_1–C_2, E_1–E_2, F_1–F_2, G_1–G_2, H_1–H_2, and J_1–J_2).

In Figure 4a it may be seen that traces are recorded without concavities being present on the sea bed and that, in comparison with the traces shown in Figure 3a, the edges of the traces are steep, particularly at T, U_1, U_2, V, W, X_1, and X_2.

Discussion

These records suggest that:—

1. The schools were cigar shaped with their longest axes along the direction of the tidal streams;
2. The edge of a school was more sharply defined where the sea bed was flat than where a concavity was present;
3. In one case, the fish shoals were lying in a trough in the sea bed (Figure 3a).

If confirmed as general, the information under (1) would be of advantage for shooting drift-nets, whether the wind was along or across the direction of the tidal stream. When the wind is in the same direction as the tidal stream the drift-nets are necessarily shot along or parallel with the long axis of the

school (Figure 5a); even at a comparatively short distance from the axis, it is likely that no fish would be caught, which may account for observed differences between the catches of adjacent drifters. When the wind is at right angles to the tidal stream, the drift-nets, shot as before in the direction of the wind, would lie across the long axis of the school (Figure 5b).

If the fish were not moving in the water, they would move over the ground at the same speed as the driving nets and hence would not be caught. If the fish were stemming the tidal stream or were swimming in the same direction as the tidal stream, they would move into the nets; the school would move with its long axis across the line of nets. The fish would be patchily distributed up and down a fleet of nets, but the sharp differences in catch between adjacent drifters would be reduced.

In order to simplify the discussion, the effect of wind on the direction of tidal stream has been ignored. The dotted line on Figure 5b represents this effect in a symbolic manner.

Summary

A description is given of the method used to determine the shape of herring schools by means of an echo-sounder and Decca track-plotter in the English Channel. The shapes of the schools are shown to be elongated, with their long axes parallel to the direction of the tidal stream. Echo-traces recorded of schools over a flat and trough-like sea bed are compared. The edge of a school was more sharply defined when recorded where the sea bed was flat.

The bearing which the shape of herring schools has on the action of drift-nets is discussed. It is suggested that the difference in catch between adjacent drifters may be due to the direction of the wind in relation to that of the tidal stream.

Diet-Induced Variation in the Free Amino Acid Complex of *Sardinops caerulea*

By

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U. S. Fish and Wildlife Service

STUDENTS of animal ecology, population dynamics, and resource management have long been faced with the problem of describing the size and integrity of the populations with which they are working. This general problem is often confused, on the one hand, by the fact that morphological differences may only be a reflection of environmental differences and not of genetic differences and, on the other hand, by the fact that genetic differences are not always reflected morphologically. Until recently, physiological and genetic laboratory techniques have been quite limited in their applicability to field problems. By the use of paper partition chromatography as a tool in biochemical analysis, it may be possible to resolve some of the differences arising between the strictly field and laboratory approaches (BUZZATI-TRAVERSO and RECHNITZER, 1953). I chose free amino acid analysis since much of the previous work had been done with this determination. In order to determine the applicability and limitations of free amino acid analysis as an aid in systematics, the following experiment was performed.

Methods

In the spring of 1954 Steinhart Aquarium received approximately 1500 sardines (RADOVICH, 1954). These fish were taken in Hipolita Bay, Baja California, and are believed to be representative of a single population.

Four tanks were made available by the California Academy of Sciences for the experiments. Each was approximately 4 feet by 2 feet and 3 feet deep, and contained about 160 gallons of water. The tanks were made of leached redwood. Sand-filtered sea water was continuously cycled through the tanks. Throughout the course of the experiment the water temperature ranged from 66° to 71°F., with a maximum daily range of $\pm 0{\cdot}5$°F.

The four tanks (C_1, C_2, P_1, P_2) were each stocked with 25 sardines. These fish were withdrawn from the main stock tanks without conscious selection.

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An additional sample of 25 sardines was sacrificed at the start of the experiment and is designated as "Control". These fish were in a starved or semi-starved condition. Fish in tanks C_1 and C_2 were fed on a high carbohydrate diet. Fish in tanks P_1 and P_2 were fed on a high protein diet. The fish were fed on a ration of 4 g. (dry weight) of food per fish per day. The ration was divided into a morning and afternoon feeding.

The carbohydrate diet consisted of tapioca dyed red to simulate brine shrimp (upon which sardines will feed in captivity). This diet contained less than 0·0025 g. of amino acid per gramme of food as determined by acid hydrolysis (SKINNER *et al.*, 1940) and ninhydrin colour test (LEDERER and LEDERER, 1953). The tapioca was about 90% carbohydrate. The protein diet consisted of fish meal, chicken eggs, vitamin supplement, and fish liver oil. This material was homogenized and fed as dry pellets. On acid hydrolysis it yielded the following amino acids:— aspartic acid, glutamic acid, glycine, threonine, alanine, tyrosine, tryptophan, proline, leucine, valine, lysine, and serine, as determined by paper partition chromatography (BRIMLEY and BARRETT, 1954). This diet was 56·94% protein and 7·08% carbohydrate.

The experimental fish were maintained on these diets for a period of six weeks and then sacrificed. Their weights and lengths were recorded, and body cavity fat was noted. A chromatogram was made of a sample of the pectoral muscle.

The muscle sample (approximately 1 mm^3.) was squashed $4\frac{3}{4}''$ diagonally from the corner of a sheet of Whatman 1 filter paper ($22\frac{3}{4}'' \times 18\frac{1}{2}''$) and allowed to dry. The excess flesh was scraped off after about fifteen minutes and the spot was dry in about thirty minutes. I believe that the amount of autolysis taking place in this short period was negligible. The component free amino acids were separated by two-dimensional descending chromatography. The first solvent was phenol/water, 454 g./170 ml. This mixture was allowed to operate for 34 hours. The chromatograms were then dried before the second run was started. The second solvent was allowed to act for 20 hours. It consisted of propionic acid/water, 224 ml./176 ml. mixed with butanol/water, 375 ml./24 ml. in a ratio of 1:1 (BENSON *et al.*, 1950). In order to develop the colour, a 0·5% ninhydrin solution in water-saturated butanol and 5% collidine was sprayed on dry chromatograms and heated for 5 minutes at 100°C. Two chromatograms were made from each fish. If a given amino acid spot appeared on either sheet it was counted as present in the fish.

Analysis of Chromatograms

The free "pool" amino acids which were identified in the pectoral muscle were:— aspartic acid, glutamic acid, glycine, threonine, alanine, tyrosine, tryptophan, and phenylalanine. Lysine, proline, serine, and valine analysis are unreliable because of the difficulties in resolving these in this solvent system. Of the eight clearly distinguishable acids, aspartic acid and alanine were chosen as the two representative amino acids to be examined in fish muscle because of their known high metabolic activity and their clear delineation on the chromatograms. Both of these primary amination products have reflected dietary change very well.

Since only the presence or absence of the acid was recorded, the number of

Table 1

Proportion of fish showing aspartic acid by K-class intervals and tests of significance

K	(X) Number of fish showing aspartic acid	$(N-X)$ Number of fish not showing aspartic acid	(N) Total number of fish	$\hat{P}$ Proportion showing aspartic acid
71–90	8	3	11	·7273
91–110	12	27	39	·3077
111–170	5	28	33	·1515
Total	25	58	83	

A: $$P = \frac{20}{50} = \cdot 400$$

$$\frac{(\cdot 7273 - \cdot 0455) - (\cdot 3077 - \cdot 0128)}{\sqrt{\frac{(\cdot 400)\ (\cdot 600)\quad 50}{(39)\ (11)}}} = 2 \cdot 313 > K_{.01}$$

B: $$P = \frac{17}{72} = \cdot 2361$$

$$\frac{\cdot 2949 - (\cdot 1515 - \cdot 01515)}{\sqrt{\frac{(\cdot 2361)\ (\cdot 7639)\ (72)}{(39)\ (33)}}} = 1 \cdot 579 > K_{.06}$$

Accept H_{ALT}: $P_{k1} > P_{k2} > P_{k3}$ at 10% level

fish (X) showing the acid takes on a binomial distribution with parameter P. An estimate ($\hat{P}$) of the parameter P is given by $\hat{P} \quad X/N$ where X is the number of successes (i.e., the number of fish showing the acid) and N is the total number of fish examined. The statistic $\hat{P}$ has an asymptotic normal distribution with mean P and variance $\frac{P(1-P)}{N}$.

It is assumed in this paper that the approximation of the sampling distribution of the sample proportion to the normal distribution holds sufficiently well to provide the basis for tests of significance. The small size of condition group k_1 (70–90) casts some doubt upon the validity of this assumption, and the conclusions drawn from the tests of significance. If we follow the lead of Clark (1928), a subjective estimate of condition is given by the condition factor K, where K is equal to the weight in grammes multiplied by 10^{7} and divided by the length in millimetres cubed. K was computed for each fish and the fish were then grouped according to K value. $\hat{P}$ was computed for each K-group (Tables 1 and 2).

Since it is desired to know whether there is an inverse relation between conditions and pooling of aspartic acid and/or alanine, we may test the null hypothesis $Pk_1 = Pk_2 = Pk_3$ against the alternative hypothesis that $Pk_1 > Pk_2 > Pk_3$; $k_1 < k_2 < k_3$. Condition groups k_1, k_2 are first compared for a difference in the proportion of fish showing acid and then condition groups k_2, k_3 are compared by the method described by Eisenhart, Hastay, and Wallis (1947). The null hypothesis may be rejected at the $\alpha/2$ level if the tests of significance applied to the pairs of groups may be rejected at the α level.

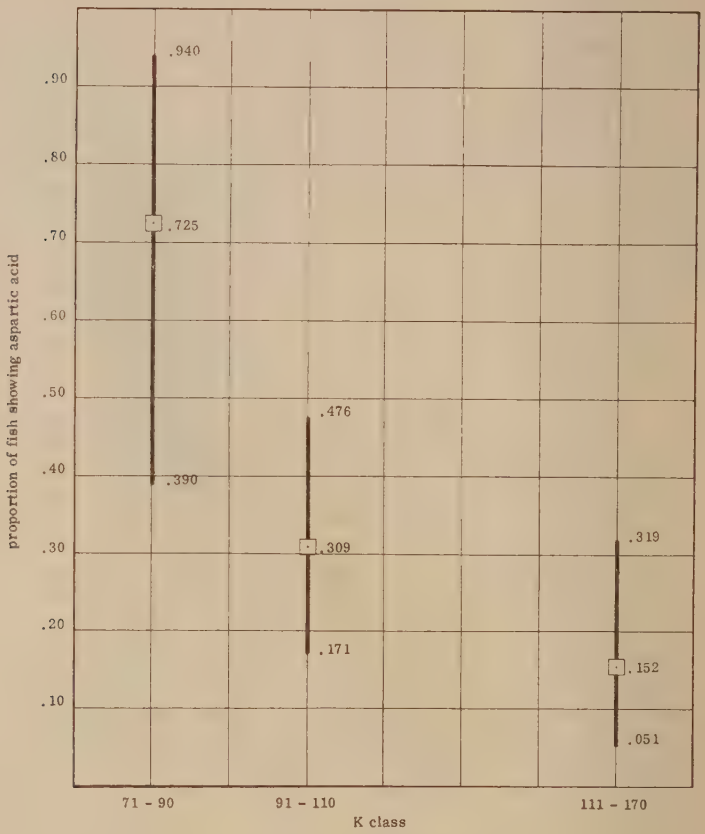

Figure 1. Proportion of fish showing aspartic acid by *K*-class intervals with 95% confidence limits.

The null hypothesis may be rejected at the 10% level for aspartic acid and at the 5% level for alanine.

The proportion of fish, by *K*-class intervals, showing aspartic acid is given in Table 1. In Figure 1, I have plotted $\hat{P}$ against *K* values. About each estimate of *P*, I have constructed 95% confidence limits. These limits were calculated from tables in FISHER and YATES (1949).

The proportion of fish, by *K*-class intervals, showing alanine is given in Table 2. Figure 2 was prepared in the same manner as Figure 1. Both figures show the same result — as the *K* values decrease, the proportion of fish showing the free amino acid increases.

In the next set of analyses, I wished to test the hypothesis that there was a homogeneous distribution of the free amino acid among the various diet groups. This is best accomplished by using analysis of contingency tables (DIXON and MASSEY, 1951). Since my numbers are small, I had to use a correc-

Table 2

Proportion of fish showing alanine acid by *K*-class intervals and tests of significance

K	(*X*) Number of fish showing alanine acid	(*N*−*X*) Number of fish not showing alanine acid	(*N*) Total number of fish	$\bar{P}$ Proportion showing alanine acid
71–90	9	2	11	·8182
91–110	19	20	39	·4872
111–170	6	27	33	·1818
Total	34	49	83	

A:

$$P = \frac{28}{50} = \cdot 560$$

$$\frac{(\cdot 8182 - \frac{1}{22}) - (\cdot 4872 - \frac{1}{78})}{\sqrt{\frac{(\cdot 5600)\ (\cdot 4400)\ 50}{429}}} = 1 \cdot 760 > K_{.04}$$

B:

$$P = \frac{25}{72} = \cdot 3472$$

$$\frac{(\cdot 4744) - (\cdot 1818 - \cdot 0152)}{\sqrt{\frac{(\cdot 3472)\ (\cdot 6528)\ 72}{128 \cdot 7}}} = 2 \cdot 734 > K_{.01}$$

Accept H_{ALT}: $P_{k1} > P_{k2} > P_{k3}$ at 5% level

tion due to continuity. These procedures estimate the differences from a calculated distribution which is based on the given distribution. These differences, which are additive, are then compared with a χ^2 table. If the calculated differences exceed those of the table, we conclude that homogeneity does not exist. The analysis of contingency tables for aspartic acid is presented in Table 3. At the 5% level of significance the protein and the carbohydrate groups cannot be shown to be the same with respect to aspartic acid. Nor can the protein and control groups be shown to be the same. The carbohydrate and control groups were the same with respect to aspartic acid at the 5% level.

Table 4 shows the differences in proportion of fish containing alanine with respect to diet group. At the 5% level of significance the protein group does not differ from the carbohydrate group. The carbohydrate group cannot be shown to be the same as the control group. Nor can the protein group be shown to be the same as the control group at the 5% level.

From the above data it is apparent that the magnitude of difference is sufficiently great to obviate the need for quantitative determinations. Since rigorous randomization procedures were not used, bias may have crept in. I believe, however, that the principle of randomization has not been seriously violated.

Fish fed on the protein diet all had fat in the body cavity. Some of the carbohydrate-fed fish had fat in the body cavity. None of the control fish had fat in the body cavity.

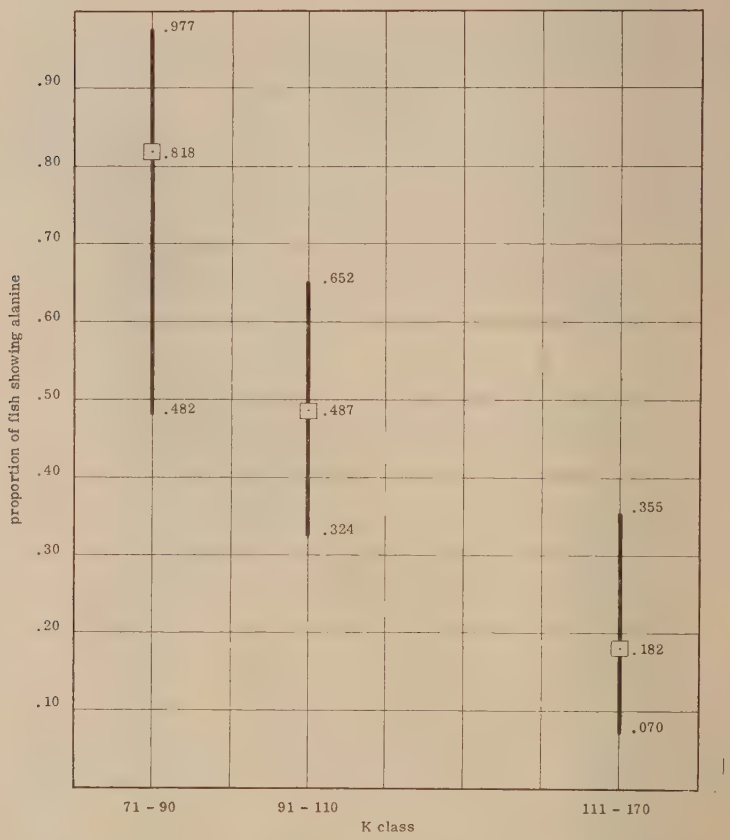

Figure 2. Proportion of fish showing alanine by *K*-class intervals with 95% confidence limits.

Discussion

As I have stated previously, these fish are believed to be representative of a single population. They were all two years old, as determined by counting scale annuli. CLARK (1928) has tabulated *K* values for a large number of San Pedro sardines. From her data, I have concluded that the normal *K* for the range of lengths in which I was working must lie between 105 and 110. At the start of the experiment the mean *K* value for these fish was below that of the San Pedro fish and their subsequent weight-length relationship suggested a shift in metabolic processes (FARRIS, 1956). Further evidence of the metabolic shift is gained from the above examination of the distribution of aspartic acid and alanine in the population.

The data of PHILLIPS *et al.* (1952) suggested that in brook and rainbow trout a shift in the efficiency of nitrogen metabolism occurs in the first week of starvation. The rate of nitrogen loss becomes progressively less as the week

Table 3

Analysis of contingency tables, with a correction due to continuity, for proportionate distribution of aspartic acid with respect to diet

Diet	Number of fish showing aspartic acid	Number of fish showing no aspartic acid	Total
Carbohydrate	11	20	31
Protein	3	26	29
Total	14	46	60

$\sqrt{X^2_c} = 1{\cdot}995$ Refer to Table VIII of Fisher & Yates

$m = \frac{14 \times 29}{60} = 6{\cdot}77$ Significant ·05

$p = \frac{6{\cdot}77}{14} = {\cdot}4836$

$$X^2_c = \left(\frac{[(11)\ (26) - (20)\ (3)] - 30}{(31)\ (29) \cdot (14)\ (46)}\right)^2 60 = 3{\cdot}9812 > X^2_{(.05)}$$

Carbohydrate	11	20	31
Control	11	12	23
Total	22	32	54

$$X^2_c = \left(\frac{[(11)\ (12) - (20)\ (11)] - 27}{(22)\ (32)\ (31)\ (23)}\right)^2 54 = 0{\cdot}4010 < X^2_{(.05)}$$

Protein	3	26	29
Control	11	12	23
Total	14	38	52

$$X^2_c = \left(\frac{[(3)\ (12) - (26)\ (11)] - 26}{(14)\ (38)\ (29)\ (23)}\right)^2 52 = 7{\cdot}353 > X^2_{(.05)}$$

progresses. In a later paper, Phillips *et al.* (1953) described an initial period of rapid weight loss followed by a period of comparatively little weight loss. Toward the end of the fourteenth week of the starvation period, the rate of weight loss rose rapidly, as did the mortality rate. This suggests to me a change in the metabolic process during the final stages of starvation. The initial change in rate of weight loss very likely is a change in the efficiency of substrate utilization, but the final rate change quite possibly is a shift in metabolic processes.

If it is true that the genome prescribes the range and limits of the enzyme complex, then the range and limits of the metabolic products are just as surely determined. Within this range, however, the effects of the internal and external environment and the effect of enzyme substrate may manifest themselves in many ways. I should like to suggest the following alternative pathways for the appearance of aspartic acid and alanine in the free amino acid pool. One source may be excessive protein breakdown and/or lack of de-amination or

Table 4

Analysis of contingency tables with correction due to continuity for proportionate distribution of alanine with respect to diet

Diet	Number of fish showing alanine	Number of fish showing no alanine	Total
Carbohydrate	6	25	31
Protein	3	26	29
Total	9	51	60

$$X^2_c = \left(\frac{[(6)\ (26) - (25)\ (3)] - 30}{(9)\ (51)\ (31)\ (29)}\right)^2 60 = \cdot 3782 < X^2_{(\cdot 05)}$$

Carbohydrate	6	25	31
Control	25	0	25
Total	31	25	56

$$X^2_c = \left(\frac{[(6)\ (0) - (25)^2]}{(31)^2\ (25)^2}\right)^2 56 = 36 \cdot 42 > X^2_{(\cdot 05)}$$

Protein	3	26	29
Control	25	0	25
Total	28	26	54

$$X^2_c = \left(\frac{[(3)\ (0) - (25)\ (26)]^2}{(28)\ (26)\ (29)\ (25)}\right)^2 54 = 43 \cdot 23 > X^2_{(\cdot 05)}$$

other enzymatic diversions. Interruption of de-amination could be brought about by lack of de-aminase enzyme synthesis. Or, perhaps, aspartic acid and alanine are no longer synthesized, the amino nitrogen travelling by an alternative pathway. Since asparagine was not identified on the chromatogram, I infer that this compound does not participate in this phenomenon. Further experiments are necessary to choose the correct interpretation from among these possibilities.

To return to the major argument that the investigation of free amino acid pools may be used as a systematic tool, the data indicate that at least two components of the "pool" vary with the environment. It has been shown that an inverse relationship exists between the proportion of fish showing alanine and aspartic acid and starved condition of the fish. While this experiment has demonstrated the variability of two components of the free amino acid "pool" which was caused by the environment, it has not defined its parameters. The dynamic nature of muscle tissue introduces a degree of variability which requires a high degree of precision in order to define. Refinement of the techniques already described may be sufficient in order to resolve the problem. On the other hand, a more stable tissue may be found, or perhaps an examination of fats and carbohydrates will reveal relationships heterofore unsuspected. When the total biochemistry of the organism is revealed, we should be able to characterize that organism at any phylogenic level we may desire.

Summary

1. The free amino acid content of pectoral muscle tissue of the California sardine (*Sardinops caerulea*) was compared by paper partition chromatography for lots of 25 fish fed on different diets. The diet history of these fish was (1) starved or semi-starved (one lot), (2) protein diet (two lots), and (3) carbohydrate diet (two lots).

2. Twelve amino acids were found, including aspartic acid, glutamic acid, glycine, threonine, alanine, tyrosine, tryptophan, phenyl alanine, lysine, proline, serine, and valine. The variability of only two, aspartic acid and alanine, was examined.

3. The proportion of fish having free aspartic acid and alanine varied inversely with the condition (K) of the fish.

4. The proportion of fish having free aspartic acid was greatly reduced in the protein-fed fish. The proportion did not differ between the control fish and carbohydrate-fed fish.

5. The proportion of fish having free alanine was much greater in the control fish. The proportion did not differ between the carbohydrate-fed fish and the protein-fed fish.

6. Possible explanations for these observed differences are given.

7. Further work is necessary before paper chromatography of free amino acids can be used without reservation as a systematic tool for distinguishing groups of less than specific rank.

8. Some areas for further work are suggested which may resolve some of the difficulty associated with this problem.

Acknowledgements

The assistance of Mr. Harold Hass, Tropic Waters Aquarium, has been extremely valuable in the preparation of the diets. Mr. Anatole Loukashkin, California Academy of Sciences, fed the fish. Mr. John MacGregor, U.S. Fish and Wildlife Service, made all the measurements on these fish. I also wish to thank Dr. R. C. Miller and Dr. Earl S. Herald, California Academy of Sciences, for making the facilities of Steinhart Aquarium available to me. Special thanks are due Dr. Raymond Barrett, Dartmouth College, whose aid and encouragement during the formulation of this problem were indispensable. The comments of Dr. E. L. Tatum, Stanford University, concerning the interpretation of results have likewise proved of great help. I am indebted to Mr. Bruce Taft, U.S. Fish and Wildlife Service, for the preparation of the statistical material.

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An Improved Instrument for Measuring Small Crustacea

By

J. Mauchline

Introduction

The standard measurement for prawn-like crustaceans is the length of the carapace from the lateral base of the eye notch to the median dorsal posterior end of the carapace. Since these two areas are not in the same plane, projection methods of measurement are subject to error.

A device which enables such measurements to be taken, without excessive error, has already been put forward (Cole & Mistakidis, 1953). This is a modified screw micrometer having a jaw fixed to each anvil, the jaw on the movable anvil being kept in the same plane as the other by a guide bar underneath the anvil. Measurements can be made with a 0·1 mm. accuracy. The author has developed a similar instrument which has certain advantages over previous models. It is considered that subjective errors are reduced to a minimum with this device.

The Instrument

The main differences in the design of this instrument from that of Cole & Mistakidis consist of the use of an overhead guide bar which is used for the floating jaw, and a spring instead of a collar, which fixes the floating jaw in relation to the micrometer anvils. There are five parts in both instruments.

A brass sleeve (Fig. 1, C) was made to fit closely round the micrometer anvils. A part was cut from this at one end and a projection was left at the other (Fig. 1, C) so that when the sleeve is slipped, almost upside down, over the fixed anvil and turned right way up it becomes locked. Inside this sleeve is the floating-jaw carrier and spring (Fig. 1, E, D). The carrier is a lapping fit and has a band (Fig. 1, E) hollowed out round it to ensure its free travel along the sleeve. The spring is placed, not fixed, on the spring housing (Fig. 1, E) so that it lies between the carrier and the fixed anvil.

The guide bar can be of any desired length but one point should be borne in mind; it not only serves to guide the floating jaw and carry the riding jaw, but also acts as a hand-rest when the operator is measuring. The bar is welded

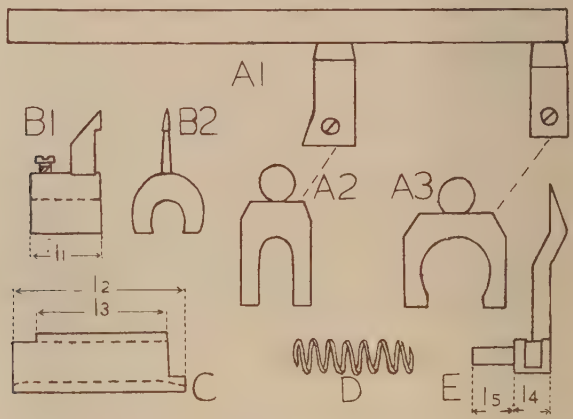

Figure 1. The special parts of the instrument. A1: the guide bar of $^1/_4$″ diameter brass rod with its two bridges. A2, 3: the two bridges and guide bar shown in cross-section. B1, 2: the rider plus jaw shown side and end on, respectively. C: the brass sleeve, outer diameter $^7/_{16}$″, inner diameter $^{17}/_{64}$″. D: the spring, $^{17}/_{16}$″ long, of diameter which gives a lapping fit in the brass sleeve. E: the jaw and carrier, the greatest diameter of which is a lapping fit on the brass sleeve. l_1, $^1/_2$″; l_2, $2^{11}/_{64}$″; l_3, $1^1/_{16}$″; l_4, $^1/_4$″; l_5, $^9/_{16}$″.

Figure 2. The instrument with the brass sleeve removed to show the spring and jaw carrier in position between the anvils.

to two bridges (Fig. 1, A1–3) which fit closely round the upper part of the micrometer body. The first bridge is held by a nut and bolt through the micrometer body, the second by screws which tighten into dimples on either side of the body.

The fixed jaw is mounted on a runner (Fig. 1, B1, 2) which is held in the required position by a screw which tightens into a groove along the median dorsal part of the bar. The jaws are set by means of precision blocks of the required length.

Since the micrometer anvils cannot close up owing to the spring and jaw carrier, the minimum set of the micrometer depends on the shape of the jaws. As COLE & MISTAKIDIS point out, it is difficult to measure prawns with carapaces less than 4 mm. The author's instrument has a minimum range of 2 mm. but the jaws could be set to give a zero measurement if required. The maximum measurement with the guide bar at present on the device is 8·5 cm. and therefore this instrument can be used for accurate measurement of larger material.

A rough perspex stand holds the micrometer at a 45° angle, and the protruding screws of the guide-bar bridges are used to lock it in position. The

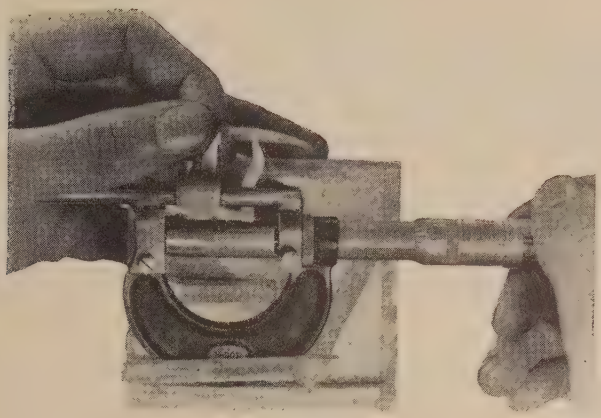

Figure 3. The instrument set in its stand, being used to measure the euphausid held between the finger and thumb.

best way to measure a crustacean carapace is to hold the animal, by the dorsal and ventral sides of the antennae, between the finger and thumb. The hand is held with the palm facing the operator, the thumb above the finger (Fig. 3). When the micrometer is held in this way the hand is in a natural position, and the dorsal part of the crustacean carapace faces the jaws of the micrometer.

The following points are worth observing:—

1. Parallax errors must be avoided by fixing the micrometer in relation to one of the operator's eyes.
2. When the floating anvil is being adjusted to measure another specimen, the micrometer should be screwed or unscrewed one or two turns. This is necessary because after one animal has been measured the micrometer has to be opened or closed to measure the next. It was found, however, that the operator's hand could not do this in one movement when the difference was more than 0·5 mm. Instead, the micrometer handle was turned a small amount several times. These amounts were found to be almost constant in size and when the measurements of several animals were examined it was found that quite often the differences between them were divisible by a whole number equivalent to the angle through which the micrometer handle was moved.
3. The posterior end of the carapace of specimens should not be dripping with water or fixative. If the carapaces are wet a reflection is obtained from the posterior dorsal indentation.

In tests, failure to observe these three points accounted for 75% of the errors occurring in high-speed work. If these instructions are followed, then accuracy can be as great as 0·05 mm., with 200 measurements per hour. Thus data for studies of growth-rates, biometrical relationships, and detailed population analyses can all be obtained accurately with this device.

I am indebted to Mr. James S. Craib for his help in designing and making this tool.

Summary

An ordinary screw micrometer was modified so that measurements could be made between two jaws, one fixed and one floating. The fixed jaw is independent of the fixed micrometer anvil, and its position relative to the floating jaw can be altered, which allows a wide range of measurements to be made independently of the size of the micrometer adapted.

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Measurement of Condition in Mussels and Oysters

By

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The relative values of subjective and objective assessments as scientific measurements have been the basis for a considerable amount of psychological research in recent years. Sheppard (1953) reviews some of the literature on the subject and says that "there seems little doubt that it is better to use objective tests when possible, if suitable ones can be designed."

Various methods have been used to evaluate objectively the condition of oysters and mussels. Medcof and Needler (1941) used a method in which the meats of 10 oysters were dried to constant weight at 100°C. and the expression

$$\frac{\text{weight of dried meat in grammes}}{\text{shell cavity in millilitres}} \times 1000$$

was used as an index of condition. This method, with or without variations has been used by many other workers in North America.

Ingle (1949) correlated the dry-meat-weight method of condition index with glycogen content on 34 samples of oysters and found a correlation coefficient of 0·69. The glycogen content as a measure of condition has been used by Galtsoff (1947) and others. Korringa (1955) used the ratio of dry weight of meat to shell contents × 100, but used a toluene distillation method for obtaining the dry weight of the meats. A method similar to the one described below, based on an unpublished report by Vahl and Townsend, was used by Odlaug (1946).

The use of dry weights or glycogen estimations in assessing quality is possibly more precise than the method described below, but because of the time needed to prepare the material, large samples cannot be used. We have found that there is a large inherent variability in the condition of oysters and mussels within a sample, and it is therefore essential to use large samples to minimize chance variations in the results. This high variability of the index of condition in a sample is due almost entirely to variability in the meat volume or weight. The dry weight of meat shows a similar variability and has a high correlation with the wet weight and volume (Fig. 1). The method described below may be less precise than other methods, but because of its simplicity and speed,

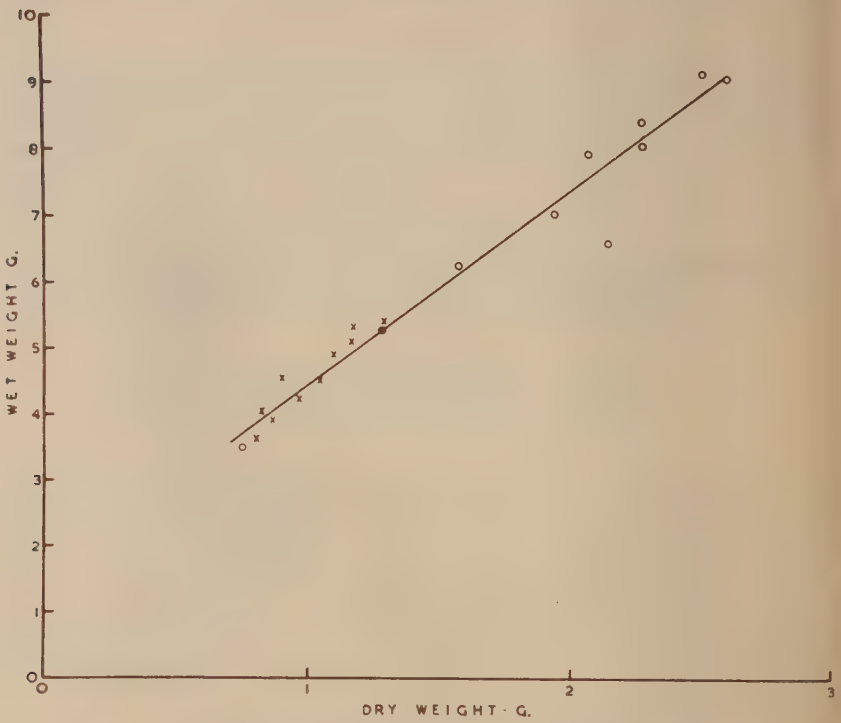

Figure 1. Correlation between wet weight and dry weight of mussel meats.
o Sub-littoral mussels of length 6·0 ± 0·2 cm.
x Half-tide level mussels of length 6·0 ± 0·2 cm.

which allows large samples to be examined, should be more accurate for determining small differences between samples from different populations. It has also the advantage that the equipment required is easily transported, and thus measurements can be done at any place without regard to distance from the laboratory.

The index of condition is assessed by measuring the volume of the shell cavity and the volume of the meat contained therein, while both are wet, dividing the meat volume by the shell cavity volume and multiplying by 100. The index of condition is therefore the percentage of the shell cavity occupied by meat.

$$\frac{\text{Meat volume}}{\text{Shell cavity volume}} \times 100 = \text{Index of Condition}$$

By this means the degree of fatness of the meats is objectively measured, irrespective of shell thickness and, to a certain extent, the size of the oysters, although a significant correlation does exist between length and condition in mussels (see below).

The volume of the shell cavity is obtained by measuring the total volume of the shellfish and the volume of the shells in a displacement jar in the case

Figure 2. Displacement jar for measuring volume of whole oysters and oyster shells.

of oysters, and a measuring glass in the case of mussels, and subtracting the volume of the shells from the total volume. Fresh water is generally used as the displacement medium.

Preparation of Material

All the samples to be examined should be treated similarly before examination. The best method is to remove the shellfish from sea water as they are required, but samples can be left several days out of water, provided that all samples are similarly treated and are still alive when examined, all shellfish that have lost their shell water being discarded. They should be placed in sea water before examination.

All extraneous growths on the shells are scraped off to avoid the possibility of uptake of water by barnacles etc., or their destruction and loss while opening, and, of course, any adherent mud is also removed.

Equipment for oysters

Volume measurements of oysters can be made by direct displacement if a sufficiently wide measuring glass is available; otherwise a displacement jar is used.

The displacement jar (Fig. 2) is made from a decapitated aspirator jar with a glass spout inserted in the bung at the bottom. The highest point of the spout should be 2 or 3 cm., and the outlet of the spout 5 or 6 cm., below the level

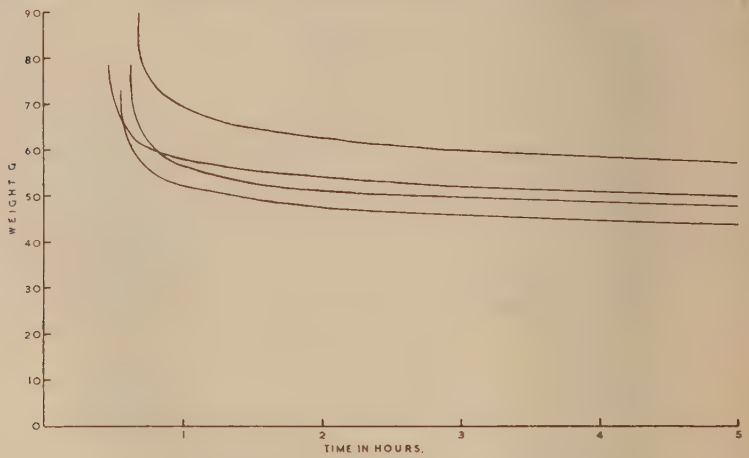

Figure 3. Loss of weight of mussel meats on drying on filter paper. Each curve represents the mean weight of four mussel meats.

of the rim. Fifty ml. measuring glasses are the most convenient size to use for measuring the volume of water displaced.

In practice a 5 mm.-bore tube has been found to be most suitable. Too large a bore spout gives too large a drop and considerably diminishes accuracy. On the other hand, a very small-bore tube takes an excessively long time to stop dripping. A 5 mm. tube takes about 25 seconds to stop dripping after the immersion of a 25 ml. object. It gives a drop size of ca. 0·13 ml. and it is accurate to within 0·25 ml., i. e., it delivers to within 2 drops each time the same object is immersed. A difference of 0·25 ml. in the volume of the whole oyster, or in the shells of the oyster, makes a difference of about 2% in the index of condition for an average 3- or 4-year-old oyster. A difference of 0·25 ml. in the meat would produce a difference of more than 5%; the volume of the meats is, therefore, measured by direct displacement in a 50 ml. measuring glass.

Equipment for mussels

For mussels the only equipment needed is a 1-litre measuring glass for the whole mussels and, afterwards for the shells, and a 100 ml. measuring glass for the meats. Volumes are measured by direct displacement.

Drying of Meats

It is necessary that the same degree of wetness should prevail for each set of whole shellfish, shells, and meats. Thus, the meats should never be left for any length of time after removal from the shell, as evaporation and drainage has been found to make a difference of up to 2·0 ml. in oyster meats in half an hour in a warm room. Figure 3 shows the loss of weight of mussel meats plotted against time of exposure. Each point on the curves represents the mean

weight of four mussels, which were first weighed wet and then placed on filter paper and weighed at intervals. It can be seen that the loss of weight, and thus volume, is very rapid during the first 15 minutes. For this reason, great care must be exercised when repeat tests are made on the same material. Even with the greatest care, experimental errors can occur; thus it has been found to be advisable to develop a routine method of examination.

Method for oysters

The method evolved at Conway is as follows:—

Two displacement jars and four measuring glasses are used. The displacement jars are set up on a firm base, preferably over the edge of a sink, with sufficient clearance to allow the measuring glasses to be placed beneath the spouts. They are mentally marked as A and B. A box is set up on the bench to allow the measuring glass to be read at eye level.

Ten oysters are laid in two rows, X and Y, and numbered consecutively from the left. All the oysters are measured for length and breadth and returned, after measurement, to their appropriate positions in the rows.

The displacement jars A and B, previously filled and allowed to level, are used for the volume measurement of rows X and Y respectively. Oyster X 1 is placed in jar A and when the dripping has stopped, oyster Y 1 is placed in jar B and allowed to drip whilst the reading for oyster X 1 is being taken and noted. The measuring glass is emptied and replaced at the spout of jar A. Oyster X 2 is then placed in jar A and allowed to drip whilst the reading of Y 1 is being taken. The operation is repeated until there are five oysters in each jar. They are then removed and replaced in their original order in two rows. The jars are topped up again. The oysters are opened from the hinge (it is important that the flesh of the oyster should not be cut during opening as this can result in loss of body fluid) and the adductor muscle severed from the convex shell. The oyster meats are lifted out of their shells with forceps by the adductor muscle, touched on both sides on a clean absorbent cloth, and each placed immediately in a 50 ml. measuring glass containing approximately 20 ml. of water. It is important to see that no air bubbles are trapped in the measuring glass and that the meat is wholly immersed. The reading of the meats is then taken and entered in the appropriate column of the record sheet. The shell volumes are now measured in exactly the same way as the whole oysters. Again the procedure continues until the five shells in each row have been measured and returned to their positions in the rows.

All the necessary information is now to hand for working out the index of condition for the ten oysters. It is advisable to do so at this stage, so that in the event of obvious errors, repeat tests can be made of the meats or shells.

Method for mussels

The method used for mussels is simpler; because of their shape and size, the total volumes and volumes of the shells can be measured by direct displacement in a 1000 ml. measuring glass.

A sample of 60 mussels is divided into four subsamples of 15. The volume of the 15 mussels is found. The 15 mussels are then opened and the meats, after having been dabbed on a clean cloth, to remove pendant drops, are put

directly into a 100 ml. measuring glass and their volume measured by direct displacement. The record sheet for mussels is as set out below:—

Length mm.	Total volume ml.	Shell volume ml.	Cavity volume ml.	Meat volume ml.	Index of condition
58					
58					
59	177	45	132	81	61·3
56					
etc.					

There is no reason why oysters should not be similarly treated, provided sufficiently large measuring glasses can be obtained. The loss of accuracy in the readings of a wide measuring glass may be compensated for by the use of large subsamples, as with mussels, with a consequent reduction in sources of error.

Seasonal variation in condition

It has been found that there is a decline in the condition of mussels at Conway, which starts in February. Considerable fluctuations about a low level occur during the succeeding months until the recovery from spawning is completed in July or August. These fluctuations, which are no doubt related to spawning, occur at different times at different places. Thus for six months of the year, February to July inclusive, comparisons of condition in mussels could give very misleading results. The same variability occurs during the breeding season of oysters. In consequence, all comparative studies of condition should be done when spawning is not in any degree possible.

Statistical Examination of Samples and Sample Size

A sample may be examined in groups of five. That is, the displacement of five oysters is measured together, five shells together, and five meats together, and the result is thus a mean of the index of condition of the five oysters. This method has many advantages; it speeds up the examination of samples and it reduces the experimental error to one-fifth. The disadvantages are that it masks anomalous results, the data provided are not so complete, especially where it is required to classify individuals within a sample, and it makes the application of statistical methods slightly less useful.

Range

Indices of condition for individual flat oysters have ranged in our tests from 19 to 80, but results below 25 and above 75 should be regarded with suspicion. (Newly imported Portuguese oysters have given an index of condition as low as 16. This may have been due to loss of shell water with consequent drying of the meats.) A reasonably uniform sample should give indices ranging from say, 30 to 60. However, the presence of a factor such as shell disease in oysters from good fattening grounds, where half the oysters may be infected, a quarter of them severely, will increase the range and the scatter of the results.

Standard deviation

The standard deviations in 20 samples of from 20 to 50 individuals ranged from 4 to 15, with an average of 10.

Significance

Application of Student's "t" test ($t = \bar{x}\sqrt{N}/\sigma$) shows that as far as generalizations are possible with such variable data, for a standard deviation of 10, a difference in the mean of 4 for samples of 25, and of 3 for samples of 50, is necessary for a difference to be significant where the samples are being compared against an arbitrary standard, and at a probability level of $P = 0{\cdot}05$.

When the difference between the means of samples is to be considered, and the standard deviation for each sample is 10, then the standard deviation of the difference of the means is the square root of the sum of the variances, in this case 14·14. With $\sigma = 14$, the difference between the means of two samples needs to be of the order of 5·6 for samples of 25 and 4 for samples of 50 with $P = 0{\cdot}05$.

Size of sample

A sample of 50 individual oysters can be examined by two persons in two hours. It has been found that if it is necessary to examine a large number of samples, 50 is the largest practicable size of sample. In addition to the time consumed, human error tends to increase when examination of too large a sample is undertaken.

Samples of 25 may be used for some purposes, but a difference in the means of 5 or 6 required for statistical significance is rarely a fine enough limit for experimental work.

A sample of 60 mussels, divided into 4 subsamples of 15 individuals, can be examined by two persons in one hour. By taking the volumes of the 15 mussels, shells, and meats as pools, one is in effect taking the means of these estimates for the 15 mussels. This reduces the range and scatter and thus the standard deviation of the results, but it also reduces N, the number of observations in each sample, to four; thus in the formula $t = \bar{x}\sqrt{N}/\sigma$ although σ is reduced, the table value of t is increased and $\sqrt{N}$ decreased, so that much the same value of $\bar{x}$ is required for significance.

Sampling of attributes

When the samples were examined individually, it was considered that the samples might be grouped by classifying them as, say, very good, good, moderate, and poor, and describing the sample in percentages of these categories. This was proposed on the grounds that the mean did not give an overall picture when a sample, as previously mentioned, might have been obtained from a good fattening ground, but the mean was depressed by the presence of another factor such as shell disease or *Polydora*, affecting a proportion of the sample.

However, even if the sample is divided into only two classes, good and poor, reference to tables drawn up from the χ^2 test, with YATES's correction, by MAINLAND and MURRAY (1952), shows that in two samples of 50, a difference of 10 (i. e., 20%) in the number of good (A's) is necessary for significance at the $P = 0{\cdot}05$ level. In two samples of 25, if there were 10 oysters classed as

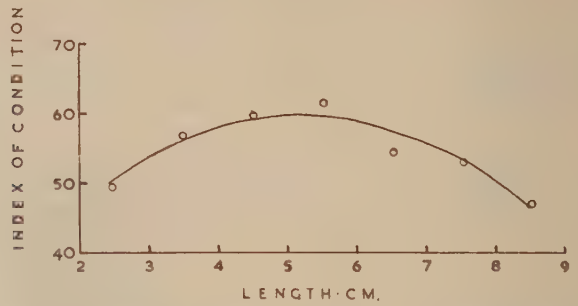

Figure 4. Correlation between condition and length in mussels with the quadratic regression line fitted to the observations.

good in sample 1, sample 2 would need to contain 18 or more good. To divide into four classes would have approximately the same effect as halving the sample. As differences of this order are rarely encountered, little is to be gained by the examination of a sample individually for the purpose of classification.

Correlation of Size and Condition

Oysters

No significant correlation was found to exist between the volume of whole oysters and their condition, in a sample of 100 individuals.

The data from a sample of 100 individuals were used. Total volume of the oyster was used as a measure of size in preference to any linear measurement of length, breadth, or depth, as the total volume expresses all these measurements. The range of total volume within the sample was from 15 to 49 ml. and the index of condition ranged from 27 to 70. The correlation coefficient had a value of $r = 0{\cdot}1265$ and was thus not significant; $P = 0{\cdot}1$.

In the case of mussels it can be seen that a linear relationship between size and condition does not exist (Fig. 4), but there is an optimum length at which the index of condition is at its maximum. In the samples examined, which were mussels dredged from the same area at the same time, the optimum length was between 5 and 6 cm. It is apparent that for assessing the differences between samples the mussels should be of approximately the same size. The correlation between length and condition is curvilinear. A quadratic regression line is fitted to the observations in Figure 4. This was done by the method described by Davies (1949) for equally spaced ordinates, with tables of orthogonal polynomials. The quadratic regression is significant at $P = 0{\cdot}01$, but not quite significant with $P = 0{\cdot}001$. The method is not absolutely valid, as all points should have equal weight. The seven points in Figure 4 are based on sample sizes of 60, 61, 62, 60, 75, 50, and 40 mussels respectively.

$$\Sigma(y - \bar{y})^2 = 195{\cdot}43$$

Source of variation	Sum of squares	Degrees of freedom	Variance
Linear	17·29	1	17·29
Quadratic	133·76	1	133·76
Interaction or Remainder	8·38	4	2·10
	159·43	6	

Variance ratio for quadratic regression = 63·7. Table value for F at $P = 0{\cdot}01$ and $N_1 = 4$ and $N_2 = 1$ degrees of freedom is 21·2 and for $P = 0{\cdot}001$ is 74·14. To sum up, no significant correlation exists between volume and condition in oysters. In mussels the correlation is in the quadratic form and highly significant.

Summary

The large variability of wet and dry weights and volumes of meats from oysters and mussels makes necessary a method that allows large samples to be measured, when objective assessment of condition is required.

Little is gained in accuracy from the use of dry weights in measurement of an index of condition. The use of volumes for whole shellfish, shells, and meats has been found to be satisfactory, with results in a form that lend themselves easily to simple statistical tests of significance. It has been shown that even with fairly large samples, it is often necessary to have comparatively large differences in the means of the samples for significance. No correlation has been found to exist between total volume and condition in a sample of 100 oysters. In mussels a high quadratic correlation has been found between length and condition, with maximum condition at lengths between 5 and 6 cm. Thus it is necessary when an index of condition measurement is used for comparative purposes, to employ samples of mussels of approximately equal size ranges. Comparative measurements should only be made when no spawning is possible.

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Reviews

K. F. Bowden. "The flow of water through the Straits of Dover related to wind and differences in sea level". Phil. Trans. Roy. Soc. London, Ser. A, **248** (953): 517–51, 18 figs. London, 1956.

Although the electromagnetic effect of flowing sea water was pointed out by FARADAY more than 100 years ago, it is only in the last 10 years that this effect has been used for estimating sea water velocities. The method of towed electrodes is now used fairly extensively, but the use of stationary submarine cables has still found only limited application, although a large number of cables are probably available for such measurements. The reason for this must be sought in part in the fact that the conductivity of the sea bottom not being known necessitates an empirical calibration on the bases of actual current measurements. Only in few cases are the currents so well known that a reliable calibration can be made. In this respect there are probably few, if any, places in the world so favourably situated as the Straits of Dover.

For his admirable work on the flow through the Straits of Dover, Dr. BOWDEN has had at his disposal a cable running across the narrowest part of the straits, and for part of the time one situated farther north also. In this case the cable was used for current recording while still being in continuous use for telephone communications. Based on LONGUET-HIGGINS's theoretical work, the conversion from potential difference to current velocity (or water transport) was made by comparison with the extensively studied tidal currents of the straits. This conversion is facilitated by the fact that the currents from surface to bottom in this shallow strait run in the same direction; the current profile, moreover, is known from previous investigations. As a valuable by-product of this calibration, the specific conductivity of the bottom material has been deduced. Elimination of the tidal currents in turn yields the residual drift currents.

Correlation of the drift current with sea level and meteorological data gives, in BOWDEN's clear and balanced presentation, many interesting results. The high value of the total correlation coefficient enables the water velocity to be represented as a linear function of local wind stress and sea level gradient. It is to be expected that both local wind and sea level are dependent on the regional air pressure distribution, and an attempt is made to correlate water velocity with regional winds. This gives, however, a less good correlation than that mentioned above, a result that probably springs from the difficulty of finding simple parameters to describe the relevant features of the pressure field. Selected periods have also been subjected to more detailed analysis, showing great diversities in the connexion between flow, sea level, and wind stress.

The theoretical treatment of the problem is in part based on previous work by the author. In view of the many uncertain factors, the result cannot be expected to agree very closely with actual conditions. BOWDEN obtains an equation between water velocity, wind stress, and sea level gradient of the same form as the regression equation obtained by statistical analysis of the observed quantities, but comparison of the coefficients gives values for the coefficients of wind stress and bottom friction nearly twice as high as are usually assumed. He suggests that the discrepancy may be due to systematic underestimation of the wind velocity, or to the fact that the condition of steady state is not sufficiently fulfilled. It may be pointed out, however, that his theory involves certain rather arbitrary assumptions in regard to the coefficients of friction, and that there is a possibility that the theory might be improved if we knew more about the frictional forces.

O. H. S.

A. Defant. "Die Strömungen in Meeresstrassen". Deutsche Hydrogr. Zeitschr., **8** (1): 1–15, 11 Abb. Hamburg, 1955.

In this paper the author surveys some of the problems related to the flow through straits. The paper was originally given as a lecture at Hamburg University, and is to some extent a summary of earlier results.

The principles applicable to the stationary state are discussed on the basis of the equations of motion, the Coriolis force being neglected. The author arrives at a rough estimate of velocity making certain assumptions about friction, and arrives at a value of a reasonable order of magnitude. A more detailed analysis gives current profiles in good agreement with observation, as shown in an earlier paper by the author (1930). Several other features of the nature of the flow in straits are also considered — the tilting of the interface between surface and subsurface currents; the difference between the depth of current reversal and that of the surface separating upper and lower water masses, etc. On the whole, this short paper contains, in somewhat condensed form, a lot of information that has hitherto been scattered over several papers.

The last section of the paper includes an interesting attempt to construct a model of the spreading of Mediterranean water in the Atlantic Ocean. This water is most easily traceable by its salinity, and the problem is treated as a two-dimensional process of stationary balance between advection and lateral turbulent salt exchange. By suitable choice of constants, the main features of the salinity distribution are fairly well approximated. The method is an adaptation of one used by the author in earlier works; it yields a value of the quotient A/v (A = lateral mixing coefficient, v = velocity) which accords well with values of the lateral mixing coefficient found by other methods.

O. H. S.

G. Dietrich & K. Kalle. "Allgemeine Meereskunde. Eine Einführung in die Ozeanographie". S. 492, 225 Abb., 23 Taf. Gebrüder Bornträger, Berlin, 1957.

During the last fifteen years the scientific effort devoted to oceanography, particularly physical oceanography, has increased enormously. The authors' main object in this book is to digest and bring together the contents of the

"bulky and widely scattered specialized literature" which has resulted from this activity. They have confined themselves almost entirely to the physics and chemistry of the sea, introducing only as much biology as is required to fulfil their second object, which is to show the inter-relation of the various branches of oceanography. To help this second purpose, for example, a section of forty-six pages is devoted to biochemistry; this is a very interesting discussion of the factors governing marine productivity.

The book is intended to be an interesting and readable account of oceanography as it stands at the present time, and is not intended as a text-book. However, it assembles an enormous amount of information and gives numerous references. It is particularly good in presenting much useful information in tables and diagrams; for example, the graph showing density of sea water as a function of temperature and salinity, though it cannot be read to great accuracy, will be appreciated by those who, like the reviewer, have tried to find this information in "The Oceans" and failed! It would, of course, be impossible for a book covering such a wide field to contain a complete bibliography, and the authors have given references only to those papers they consider to be most important; even so, the bibliography covers fourteen pages.

A good feature of the book is the way arguments are supported, where possible, by facts and figures. For example, in the discussion of the possible ways of measuring salinity, it is pointed out that the difficulty of using indirect physical methods — that is, by measuring density, electrical conductivity, and so on — lies mainly in the great temperature dependence of these properties. This argument is supported by a table of the accuracies to which temperature has to be measured to give an accuracy equivalent to $0{\cdot}02\,^0/_{00}$ salinity (0·025°C. in the case of electrical conductivity). The reviewer has chosen this example, since it gives him the excuse to point out incidentally that, in fact, the problems of measuring conductivity in a laboratory aboard ship now appear to have been overcome, and it is possible to obtain by this method a consistency approximately ten times better than is obtainable by chemical titration, and the measurements take much less time[1]). This method is being tried by most oceanographic laboratories, and seems likely to be adopted as a standard method before long.

It is probably inevitable that individual oceanographers will feel that their own branch of the subject has not been given its fair share of attention in this book, and the reviewer is no exception! Surface waves are one of the most important aspects of physical oceanography from the economic point of view, and also have considerable military importance. The sum spent in the British Isles alone on coastal engineering runs into several tens of millions of pounds each year, and a large proportion of this goes in defence against the effects of waves. The reviewer has no figures for the cost to British shipping of the delays caused by rough seas, but it must easily exceed a million pounds a year. More and more borings are being made off shore for oil and coal, and these operations are made much more difficult and expensive by the need for protection against waves. For reasons such as these, a great deal of effort has been put into the study of waves in recent years, and it is disappointing to find only a small section, of twenty pages, devoted to surface waves and just over two pages to their measurement.

[1]) The description of the successful instrument is contained in an unpublished report, No. 56–20, from Woods Hole Oceanographic Institution, "A conductivity bridge for the measurement of the salinity of sea water" by A. L. Bradshaw and K. E. Schleicher.

The authors' account of waves is readable and is developed in a logical manner, but it is written from a rather old-fashioned point of view. Most recent advances in wave studies are based on the concept of the frequency spectrum, and on the associated concept of waves as random gaussian processes. The study of the statistical properties of waves is one study based on these concepts and is most important for practical purposes. It is thus disappointing to find that the wave spectrum is mentioned only briefly, and the statistical properties of the sea surface are not discussed at all. The only mention of the directional properties of waves is to say they cannot be measured. Admittedly this important problem has not been solved satisfactorily, but several papers on the subject have been published, notably those by N. F. BARBER.

The reviewer does not feel so competent to judge the other sections. He has, however, made sure in several cases that important ideas and theories were mentioned and in each case this was so. Some of the introductory passages are rather difficult to follow, but where more practical matters are being dealt with the presentation is clear and logical. Topics covered by the book are: — topography of the sea bed, sediments, and the origin of bottom features; physical and chemical properties of sea water; oceanographic instruments and methods; heat content of the oceans; distribution of temperature, salinity, density, and ice in the oceans; theory of ocean currents; surface waves and internal waves; long waves, particularly tides; regional oceanography (deep circulation and hydrographic regions).

To sum up, the book is very well produced and has good author and subject indices. The classified bibliography and the clear and well arranged tables and diagrams already referred to are useful for ready reference, and to people who read German easily the book will give a good introduction to those branches of oceanography with which they are not familiar.

M. J. Tucker

K. Kalle. "Chemische Untersuchungen in der Irminger See im Juni 1955". Ber. Deutsch. Wiss. Komm. Meeresf., **14** (4): 313–28, 28 Abb. Stuttgart, 1957.

This paper gives an account of the chemical investigations carried out on the "Anton Dohrn" expedition to the Irminger Sea in June 1955.

Chemical investigations were made at 50 stations, most of which were located in the Irminger Sea proper. The chemical work included determinations of inorganic phosphates, dissolved oxygen, fluorescence, and turbidity. These chemical properties are illustrated in the paper by charts and vertical sections.

The most outstanding feature in the phosphate distribution is the well known maximum at intermediate depths. This maximum, as well as the lines of equal phosphate content in general, slope downwards from west to east across the North Atlantic. The author points out the interesting fact that the inclination of the phosphate isolines is similar to that of the isopycnals. A characteristic of the Irminger Sea, the author finds, is two distinct regions of phosphate maxima, separated by an intermediate region with lower values. In the Gulf Stream area off northern Scotland, relatively low phosphate values were found, both at the surface as well as in the deeper layers. At one station north of the Iceland-Greenland Ridge, low phosphate values were found, especially in the deeper layers, but as the author rightly remarks, one can hardly draw the conclusion from this material alone that the phosphate

concentration in the Iceland Sea as a whole is relatively low. However, it might be remarked here that investigations made by the reviewer in recent years indicate that such is the case.

The distribution of dissolved oxygen (expressed as the percentage saturation) was found to be much more complicated than the phosphate distribution. However, certain main features were similar for both properties. Thus an oxygen minimum was found to coincide roughly with the phosphate maximum at intermediate depths, and in the central Irminger Sea, between the two regions with maximum phosphate concentrations, high saturation values of oxygen were found. Therefore, in the central Irminger Sea, the water seems to be relatively well aerated. At the station north of the Iceland-Greenland Ridge relatively high oxygen values were found, coinciding with the low phosphate concentrations. In agreement with Professor KALLE's findings the reviewer has also found (cf. *Bulletin Hydrographique* for 1954) decidedly higher saturation values at depths between 300 and 1000 m. in the Iceland Sea than south of the Iceland-Greenland Ridge.

The fluorescence was determined by the method recently developed by the author. This is the first time fluorescence has been determined for the open sea. In some respects this property was correlated with the phosphate distribution. Thus, coinciding with the intermediate phosphate maximum, a fluorescence maximum was also found. Above the fluorescence maximum was a pronounced layer of minimum values. In the central Irminger Sea low fluorescence concentrations were found with decidedly higher concentrations near the coastal areas. However, at the station in the Iceland Sea, north of the Iceland-Greenland Ridge, characterized by the low phosphate and high oxygen concentrations, high fluorescence concentrations were found.

The main features of the turbidity distribution were found to be entirely different from those found for the other properties. Thus, turbidity maxima or minima were not found at intermediate depths, but in general the highest values recorded were in the surface layers. The central part of the Irminger Sea consisted mainly of relatively clear water, whereas decidedly more turbid water was found in the southernmost part of the region investigated.

Some of the best fishing grounds in northern Europe are located on the various banks in the shallow regions surrounding the Irminger Sea. The biological conditions on these grounds may be largely determined by processes taking place in the Irminger Sea. Studies of the chemical and physical properties in this very interesting area may therefore be of great practical importance. Professor KALLE's valuable contribution should be a definite encouragement to further work.

U. S.

Th. Stocks. "Der Boden der südlichen Nordsee. 2. Beitrag. Eine neue Tiefenkarte der südlichen Nordsee". Deutsche Hydrogr. Zeitschr., **9** (6): 265–80, 7 Abb., 1 Taf. Hamburg, 1956.

The work under notice links up with that of JARKE earlier reviewed in this journal[1]). Instead of having (as at one time expected) types of bottom and depth contours shown on one chart of the area, we are now presented with a separate and very handsome coloured bathymetric chart which can be laid

[1]) J. du Conseil, **23** (1): 98–99

over that of JARKE in perfect register. The area coverage is again between 51°20′ and 55°20′N. latitude, and from 9°10′E. to 2°W. longitude. In point of quality the production fully maintains the high standard expected of the German Hydrographic Institute, and many workers on various problems of fisheries research, on bottom deposits, on currents, and on the palaeogeography of the area, will warmly welcome this new aid placed in their hands.

It is a feature of the new chart that the depth markings are referred to mean sea-level on the argument that true morphological isobaths have a special value as compared with the depth contours usually inserted on charts which have regard for what STOCKS calls "nautical danger lines". The author declares that the latter cannot be nearly so well connected up with the contours on maps of mud flats and of the dry land.

He sees in his practice of stating sea depths in metres below M.S.L. an effective escape from the troubles which exist when reference is to a chart datum which is not the plane of reference valid for all countries, but he remarks upon the present impossibility of correctly connecting the new chart depths with land heights given on maps of the countries which adjoin the area of sea now re-charted bathymetrically.

The author uses 10-metre depth intervals and has plainly gone to great pains to establish the course of his contours. His coloured areas connoting depth depend upon the use of ten tints, ranging from a dull, brownish grey for mudflats, through gradations of yellow, green, and blue, up to a dark blue for areas carrying more than 80 metres of water.

STOCKS reproduces the German Hydrographic Institute's chart of co-range lines (spring tides) and gives a very interesting chartlet of the Wash (taken from the official German chart), whereon he shows the difference in position and course of his own depth lines referred to M.S.L. from those appearing on the navigational chart. Following a set of six chartlets which show the generalized depth divisions of the southern North Sea as earlier portrayed by GROLL, SCHUMACHER, LÜDERS, STAMP, SCHULZ, and STOCKS in the years 1915, 1927, 1931, 1936, 1937, and 1956 respectively, there comes a panel of six more chartlets which concern palaeogeography. We are shown the conjectured courses and the debouchment positions of the pre-Elbe and the pre-Rhine before the Litorina transgression.

It is a most informative exercise to lay the two charts of STOCKS and JARKE in congruence upon a tracing table and, by switching the light on and off, to study with ease and speed the association between the various bottom types and the depths over which they occur.

This is indeed a useful work and the author is to be much commended upon the fruit of his great industry.

J. N. Carruthers

P. M. van Riel. "The Bottom Water. Chapter II: Temperature". The Snellius Expedition in the Eastern Part of the East Indian Archipelago 1929–1930. Vol. II, 5 (2). Leiden, 1956.

Das Hauptproblem der "Snellius" Expedition 1929/30 war gegeben durch die Fragen nach der Bildung und der Erneuerung des Bodenwassers innerhalb der zahlreichen Tiefenbecken des Ostindischen Archipels. Der Leiter der Expedition P. M. VAN RIEL hat bereits vor dem 2. Weltkriege in mehreren Lieferungen des Expeditionswerkes dieses Problem besonders mit Hilfe der

potentiellen Bodentemperaturen diskutiert. Auch die neue, 1956 erschienene Lieferung der ozeanographischen Ergebnisse trägt den Titel: "The Bottom Water", Chapter 2: Temperature. Jedoch sein wahrer Inhalt umfaßt mehr als nur die Temperatur des Bodenwassers, denn sowohl im Text, als auch in den Vertikalkurven und Längsschnitten wird die thermische Schichtung in den verschiedenen Becken für alle Tiefen zwischen 1000 m. und dem Tiefseeboden zur Darstellung gebracht und diskutiert. Hierbei werden auch Ergebnisse erzielt, die durch ihre methodische Bedeutung von speziellen ozeanographischen Interesse sind, wie zum Beispiel eine Bearbeitung der mittleren Abweichungen der Tiefentemperaturen, die sich durch periodische (jahreszeitliche und jährliche) Einflüsse, sowie durch unperiodische Störungen an den wiederholt auf derselben Position durchgeführten Serienmessungen ergeben haben. Es ist bemerkenswert, daß innerhalb des Celebes- und des Banda-Beckens die mittleren Abweichungen sich nur zu 0·02° in 2000 m., 0·01° in 2500 m. und 0·009 in 3000 und 4000 m. Tiefe herausgestellt haben. Dies ist ein erneuter Beleg dafür, daß auch hier, wie auch sonst in den großen Tiefen des Weltmeeres innerhalb der tropischen und subtropischen Region quasistationäre thermische (und auch haline) Bedingungen existieren. Aus den Längsschnitten und besonders aus einer neuen farbigen Karte der potentiellen Bodentemperatur geht deutlich die enge Beziehung zwischen dem Relief und der Ausbreitung des Tiefen- und des Bodenwassers hervor. Nunmehr ergänzt VAN RIEL seine früheren Studien auch durch Schnitte und Karten über die vertikale Verteilung der tatsächlichen Temperatur (*in situ*) für die Tiefen ab 1000 m. Hierbei beschäftigt er sich besonders mit der methodisch wichtigen Frage der Beziehung zwischen dem intermediären Temperaturminimum innerhalb der einzelnen Becken und der Satteltiefe der benachbarten Schwellen. Der normale Fall ist, daß das durch den adiabatischen Effekt verursachte intermediäre Temperaturminimum in den Becken tiefer gelegen ist als die Satteltiefe der Eingangsschwelle. Aber es gibt, wie VAN RIEL zeigt, in den Becken des ostindischen Archipels Beispiele, wo das Umgekehrte der Fall ist oder beide Tiefenlagen übereinstimmen. Dr. P. GROEN hat zu diesen mehr beschreibenden Betrachtungen VAN RIELS die theoretischen Grundlagen beigesteuert für eine mehr kausale Deutung der von Becken zu Becken variierenden Tiefenlage dieses intermediären Temperaturminimums. Er hat gezeigt, daß sie wesentlich abhängt vom vertikalen Gradienten der Temperatur dicht über der Schwelle und in manchen Fällen auch von den thermischen Verhältnissen in den vorangehenden Nachbarbecken. Natürlich spielt auch der vertikale Wärmeaustausch, der auch vom vertikalen Temperaturgradienten abhängig ist, eine Rolle. Die Arbeit, die also eine Reihe von Spezialitäten der thermischen Schichtung im Tiefen- und Bodenwasser der ostindischen Becken behandelt, schließt mit einer neuen Karte der tatsächlichen Bodentemperatur (*in situ*) und mit einem Anhang, in welchem erneut der Wasseraustausch in der Lifamatola-Straße (zwischen dem Batjan- und dem Buru-Becken) und innerhalb des Aru-Becken behandelt wird.

G. Wüst

K. Wyrtki. "The computation of oceanic and meteorological fields of motion with friction proportional to the velocity". Penjelidikan Laut di Indonesia, **2**: 1–26, 8 figs. Djakarta, 1956.

In this article a method for the calculation of the mass transport of currents

is developed, based on the hydrodynamical equations of motion; it is assumed that the wind stress at the sea surface and the distribution of pressure are known. For the computation of the pressure distribution it is necessary not only to know the density distribution, but to make an assumption with regard to the depth of no motion. On the assumption that the frictional terms (lateral as well as vertical) can be combined into a single term proportional to the mass transport, the equations of motion can be simplified to a system of algebraic equations from which the mass transport can be easily computed.

The purpose of WYRTKI's work differs from that of the methods developed by SVERDRUP, MUNK, HIDAKA, and others, who only wished to demonstrate that the wind is the principal driving force of the current system in the upper layer of the hydrosphere. WYRTKI, on the other hand, accepts their findings and gives a simple method for actual computation of current velocities from hydrographical and wind data. The author assumes that the pressure field is known from oceanographic serial observations; accordingly the pressure field does not need to be calculated from the wind field and the boundary conditions. This has the advantage that the calculated currents not only cover wind-driven currents but also include currents arising from thermohaline circulations, however small they may be. Moreover, the theory on which the computation of the pressure field from the wind stress and the boundary conditions rests is still far from being complete, and in any case the density distribution has to be known to some extent. Thus in both cases oceanographical serial observations are necessary. Given the pressure field, WYRTKI is able to calculate the vertical velocities at the foot of the layer considered by means of the equation of continuity. The solutions remain finite when the equator is crossed, as is also the case in SVERDRUP's solution.

The main advantage of WYRTKI's method is that for a solution one does not need any boundary values of the current field because the equations are algebraic.

In principle this method claims to include lateral as well as vertical friction. In the examples, WYRTKI has considered only cases in which the vertical friction is predominant. Practice should show whether this method is reliable in areas in which lateral friction becomes important. Since the value of the friction parameter, defined as the factor of proportionality by which the value of the mass transport has to be multiplied in order to obtain the frictional stress, may be different for different regions, this parameter has to be determined, for every region considered, from a comparison between calculated and observed values of mass transport at certain places in that region. Moreover, the value of the parameter may be subject to seasonal fluctuation, as WYRTKI showed to be the case for the China Sea.

In this article only stationary currents are considered, though time dependency could be included; this would make the computations far more lengthy, however, and would require, moreover, a knowledge of the development of the pressure distribution over a period of time.

According to WYRTKI, the value of the friction parameter can best be determined from the angle between the vector of the mass transport and the "stress vector", the latter being the vectorial sum of the wind stress and the vertically integrated pressure-gradient force.

WYRTKI's examples show that the value of the friction parameter is larger for shallow water than for deep. The deduction of the relation between the

friction parameter and the vertical velocity distribution (pp. 10, 11, 12) is not quite correct since it has been assumed that k is a constant, while in fact it depends very much on the distance from the bottom. This paragraph, however, could be omitted without invalidating WYRTKI's results.

The meteorological application presented is rather doubtful and the result is identical with the old theory of GULDBERG and MOHN of 1875. The author has computed the wind field appropriate to certain types of pressure fields; the results were reasonable.

As to the oceanographical applications, WYRTKI has derived the current velocities in the upper layer of the equatorial Pacific, where the classical methods, in which the friction at the foot of the layer is neglected, yield velocity values which are too high. From the equation of continuity the vertical velocities were computed, and show regions of convergence and divergence which accord with observation.

The velocity field averaged vertically shows a conspicuous decrease in the strength of the South Equatorial Current near the equator, which seems to be due to the equatorial undercurrent.

Finally, WYRTKI has succesfully applied his method to the computation of total transport through straits and channels.

In conclusion we may say that WYRTKI's method seems to be very convenient for the calculation of stationary or quasi-stationary current fields from the wind field and the three-dimensional mass distribution in the sea, especially in equatorial regions. Practice should show, however, to what extent the results are reliable, that is, how far the simplifying assumptions made with regard to the frictional forces are permissible.

M. P. H. Weenink

G. Veronis. "Partition of energy between geostrophic and non-geostrophic oceanic motions". Deep-Sea Res., **3** (3): 157–77, 9 figs. London & New York, 1956.

This important theoretical study deals with the response of a two-layer ocean to a transient wind stress. It is a continuation of earlier work by ROSSBY (1938), CAHN (1945), BOLIN (1953), and VERONIS & STOMMEL (1955). Three problems are dealt with: (1) the quantitative partition of the energy imparted to the ocean by the wind, between non-geostrophic motions and the resulting geostrophic current; (2) what is the character of the non-geostrophic motions? (3) what is the character of the geostrophic motions?

A laterally limited distribution of wind stress is prescribed, so that a wave mechanism for the "escape" of non-geostrophic energy from the source region is included. Attention has been confined mainly to cases where the wind blows for periods not exceeding half a pendulum day, so that strong non-geostrophic motions occur in the form of inertio-gravitational oscillations.

The percentages of input energy absorbed by these non-geostrophic motions are found to be 74, 51, and 11% when the momentum is added impulsively, over a 6-pendulum-hour period, and over a 12-pendulum-hour period respectively.

The inertio-gravitational oscillations appear to be almost exclusively confined to what is called the internal mode or baroclinic mode (i. e., the mode of behaviour that is comparable to the well known internal gravity waves, where

the density interface separates two opposite régimes of motion and where the deviation of the interface from its equilibrium position is a magnified reflection of the free-surface disturbance). These motions are mainly inertia oscillations having a period of about half a pendulum day.

The character of the geostrophic response of the ocean is dependent on both the time and space scales of the momentum input. It becomes more baroclinic (with no current in the deep layer) the longer the time scale. For relatively short periods it depends upon the space scale; for large-scale flow most of the geostrophic energy is then contained in the barotropic mode.

The process of adjustment of the system is studied quantitatively.

Finally, an asymptotic solution is derived which is valid in the neighbourhood of the stream for large values of time.

P. Groen

M. Demir and **A. Acara.** "Biological and hydrological factors controlling the migration of mackerel from the Black Sea to the Sea of Marmara". Gen. Fish. Council for the Mediterranean, Proc. and Tech. Pap., 3: 365–76, 6 figs. F.A.O., Rome, 1955.

The paper is based mainly on the results of fishing by jig for mackerel between the end of April and July 1954 and on some contemporaneous bathythermograph observations, all at a great many stations in the Sea of Marmara.

The time covers the last part of the spawning season in the Sea of Marmara and most of the migratory phase when the adult mackerel are passing through the Bosporus to the Black Sea.

It was found by observation in 1952 and 1953 that the adult mackerel began to migrate to the Bosporus from the Black Sea when the surface temperature in the Bosporus was about 20°C., which occurred in October, and that they had left the Black Sea when its surface temperature was 8°C.

In the Sea of Marmara, when the temperature of the brackish upper water was less than 7–8°C., they were found exclusively in the warm Mediterranean water layer, i. e., below 40 m. depth although the amount of plankton was very much larger in the upper water layer than in the lower, but they moved into coastal water as soon as the surface temperature was about 11–12°, even though the temperature at 15–20 m. depth was still 7–8°.

Some spawning began in March and while the mackerel stayed in the lower water layer the eggs were found only in water of over 60–65 m. depth, but the main spawning took place in the brackish water layer when the mackerel had moved inshore, i. e., by 26. April 1954.

The bulk of the adult mackerel passed through the Bosporus between the end of May and the beginning of July, as is normal. Some adult stragglers do not pass through the strait before August. A minor part of the first arrivals have not spawned when they enter the Black Sea. The authors suppose that these fish have remained during winter in the cold north-eastern parts of the Sea of Marmara or in the Bosporus and that their eggs would not develop if they were spawned in the Black Sea.

The young mackerel, 11–12 cm. long, travel through the Bosporus to the Black Sea in July.

It is stated that the migrations through the Bosporus may also be governed

by the effect of the wind on the hydrographical conditions and that they may sometimes even be temporarily stopped by the reversal of the currents.

These detailed investigations have provided much interesting information about the biology of the mackerel in these regions. No doubt further information of practical value to the fishermen could be produced if regular observations of salinity and temperature were made at various depths at selected stations, since fluctuations in the hydrographic conditions appear to be closely related to the fluctuations in the yield of the fishery.

Aa. J. C. Jensen

G. Alm. "Artificial hybridization between different species of the salmon family". Rep. Inst. Freshw. Res., Drottningholm, **36**: 13–57, 8 figs. + 3 pl. Lund, 1955.

Artificial hybridization has been carried out with the following species of the Salmonidae: — salmon, sea trout, brown trout f. *lacustris*, brown trout f. *fario*, char, and brook trout, and it has been shown that it is possible to produce F1 hybrids between the majority of these species and, in many cases, to rear fully grown hybrids of ten to eleven years old. The aim of the experiments has been the examination of the rate of mortality in the crosses and the rate of growth, appearance, sexual maturity, and fertility of surviving individuals.

Mortality was found to be greater for hybrids than with intraspecific breeding and this has been related to various causes, including disturbances in the chromosome balance. In support of this contention, it has been shown that the rate of mortality in the crossings reflected the nearness or otherwise of the parents' generally accepted systematic position, it being lowest in the char × brook trout crosses and highest in the trout × char and trout × brook trout crosses. The same relationship applied to sexual maturity and fertility where, although in all the series of hybrids obtained a greater or lesser number became sexually mature, the capacity to form fertile eggs or milt was in the same proportion as the early mortality. Intercrossing and backcrossing only succeeded in the char × brook trout crossings but the mortality in the F2 was greater than in the F1.

As the author points out, the majority of the hybrids have no practical value, although the hybrids of the trout × char and trout × brook trout crosses with their light vermicular markings on a dark background may be of some interest as curiosities in ponds. However, the char × brook trout hybrids, which showed a good growth-rate, a comparatively low mortality, and a fair tolerance of high water temperatures, could be useful for stocking small lakes. Also sea trout × salmon hybrids would be useful for salmon hatching and rearing experiments.

Included in the paper is a review of literature on hybridization experiments with the Salmonidae together with some reference to work done on the Cyprinidae. The reasons for the probable lack of hybridization in nature in the Salmonidae are discussed.

The paper is furnished with tables and graphs to illustrate mortality and growth-rates, and there are three pages of interesting photographs of the hybrids obtained in the experiments.

B. Stott

J. Rahn. "Untersuchungen über Alter und Wachstum des Aalbestandes im Sakrower See". Zeitschr. Fisch. u. d. Hilfswiss., **4** (3/4): 235–56. Radebeul & Berlin, 1955.

The Sakrower See is a small lake south-west of Berlin with an area of about 0·4 square miles and a greatest depth of 35·9 m. Since 1951, electric fishing lhas been carried out in the lake on a limited scale. The aim of the investigations under review was to survey the age composition and the growth-rate of the eel population of the lake. This survey was meant to serve as the basis for ater investigations on the effect of an intensified electric fishery on the eel population.

The material consists of 666 eels caught during May–August 1952 and June November 1953, mostly by electric fishing in shallow water. Data are given on the length, weight, shape of head (subjective estimation), and (for 1953) sex of the eels. Scales were taken from the region of the body between the lateral line and the dorsal fin above the anal region, where the first scales are formed. The otoliths of only 26 eels, caught on 6. November 1953, were examined. The numbers of eels in the yellow and silver stages are not stated.

In assigning the eels to the different age-groups the author followed the method used by Marcus and Wundsch, and counted only the number of completely formed winter zones of the freshwater period. The eels caught on 6. November 1953 did not have completely formed winter zones on the edges of the otoliths. If the author found one, for instance, in which the otolith had eight complete winter zones and a ninth, incomplete growth-zone, he placed it in Group VII.

The age of the eels was in most cases determined by reading the scales and adjusting this estimate by the difference between the numbers of growth-zones in readings from the otoliths and from the scales. In most cases the author found this difference to be 3, yet there was a tendency for larger differences to occur with increasing age. This indicates that the eels of the Sakrower See usually form their first scales in the fourth year of freshwater life.

The eels in the sample were between 40 and 95 cm. in length. As the sample came from ordinary commercial catches the material contained no smaller eels. The mean length for age-groups IV–XIII were 45·8, 49·3, 52·5, 55·4, 60·9, 68·0, 70·6, 71·5, 84·0, and 85·5. The proportion of the sample contained in each of these age-groups was 1·8, 18·0, 34·0, 26·5, 10·8, 5·0, 2·7, 0·7, 0·3, and 0·2%. The fact that Groups IV and V contain fewer eels than Group VI is evidently a consequence of selective fishing. The author found no males at all in the sample.

Onwards from age-group VII the number of eels diminishes with increasing age; this is evidently a consequence of the seaward migration which takes place after $7\frac{1}{2}$ to $10\frac{1}{2}$ years of freshwater life.

Length for length, the sharp-nosed eels in the sample were heavier, on the average, than the broad-nosed eels. The author connects this with the fact that sharp-nosed eels usually grow more slowly than the broad-nosed, and with the fact that with increasing age, eels tend to grow relatively thicker through the body. In the middle groups the broad-nosed eels were about two years ahead of the sharp-nosed in regard to length. The growth of the scale was found to take place in the course of 6 to 8 weeks in summer (May–September).

It was also found that a large number of the sharp-nosed eels inhabited the same part of the litoral zone as the broad-nosed.

Many valuable observations are recorded in this work, and we may look forward with great interest to the promised work on the consequences of an intensified electric fishery on the eel population in the Sakrower See.

S. S.

Current Bibliography

Prepared by A. R. Margetts

Note. The scope of the Bibliography is limited in the main to the area covered by the Council's activities, but there are included papers of general interest relating to other areas in North Temperate and Arctic regions and exceptionally elsewhere. Limnological references are not as a rule given but papers relating to brackish waters and to salmon and freshwater fish studied by the Council are included.

Subscribers and those on the distribution list will receive regularly upon application to the General Secretary copies of the Bibliography printed on one side of the page only, for use in making up card indices.

The Editor will be glad to be advised of emendations and additions to the Bibliography.

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